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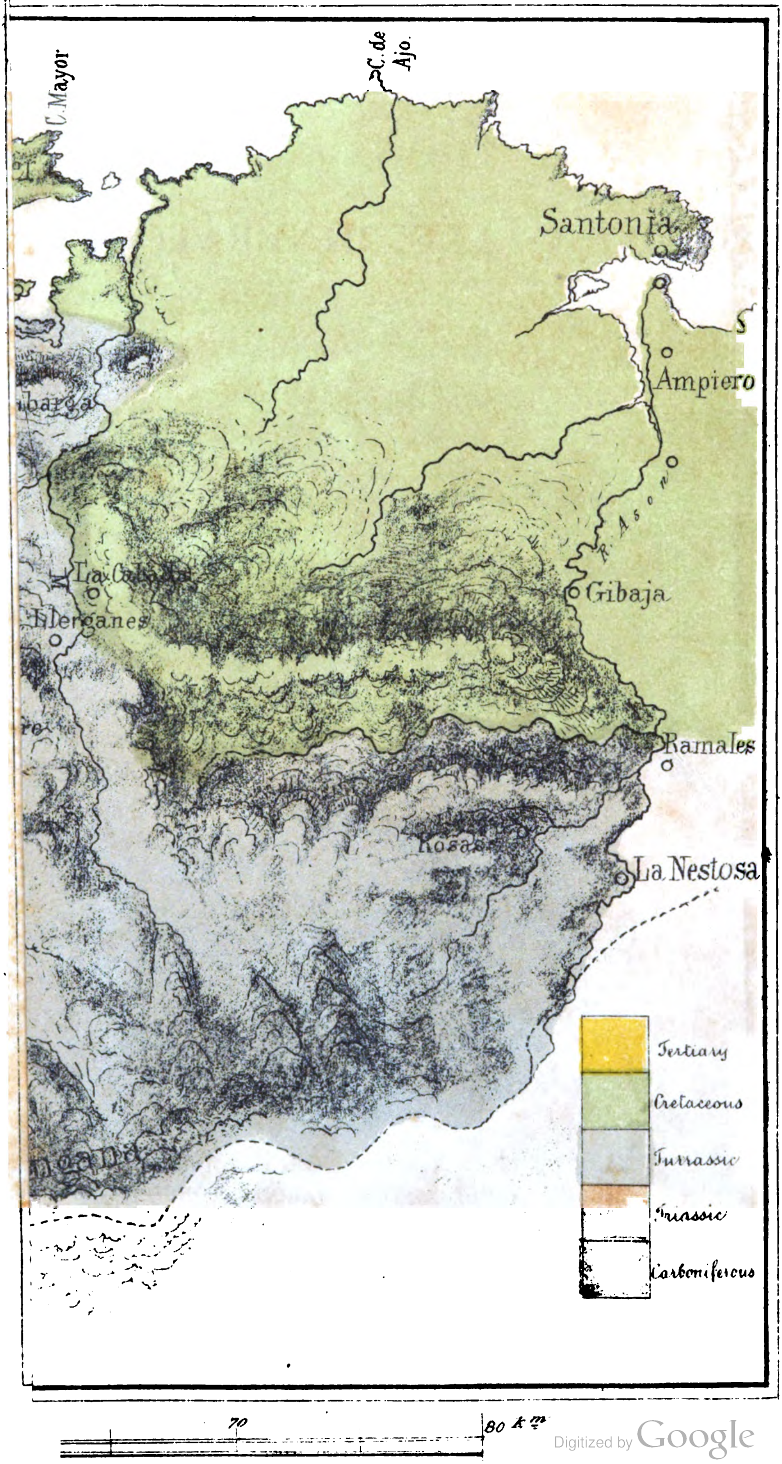
Plate I.


C. Mayor
C. de Ajo.
Santonia
Ampiero
R. Ason
Gibaja
barga
La Cabada
Lierganes
Ramales
Rosas
La Nestosa
ngano
Tertiary
Cretaceous
Jurassic
Triassic
Carboniferous
70
80 km

NOTES

ON THE

GEOLOGY AND MINERALOGY

OF THE

SPANISH PROVINCES

OF

SANTANDER AND MADRID.

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NOTES ON THE GEOLOGY AND MINERALOGY

OF

THE PROVINCE OF SANTANDER.

GEOLOGY OF SANTANDER.

THE Province of Santander, or, as it is more characteristically called by the Spaniards, "La Montaña", was until quite recently looked upon as a poor and sterile region. The peculiar physical features of the province, composed as it is of a continuous succession of unproductive or inaccessible mountain chains, and narrow and comparatively limited valleys, and without any of those large level plains which constitute the basis of the wealth of the central provinces, was no doubt the cause of this reputation; while the imperfect state of its roads, and the ignorance and depreciation of agricultural science and pursuits which necessarily resulted from a deficiency of the means of internal communication, and lastly, the ignorance which prevailed regarding its mineral wealth, apparently justified it. However merited this reputation may be, if we contrast the province with the more fortunate ones of the south, it was on the whole, however, exaggerated, and is gradually disappearing, as the resources of the province are being more fully opened up.

The causes above cited, in conjunction with the unsettled political state of the country during the first half of the present century, have prevented, or at least considerably retarded, the carrying out of the scientific study of the province, either as a private enterprise or as a governmental measure. Happily, however, for the province and for science, the active development of the School of Mines, and the coincidental discovery of several rich mineral deposits in different parts of the province during the last ten years, have necessarily led to the detailed study of its geological and mineralogical features. To the government engineers has naturally fallen the heavier part of the work, and if the public does not already possess the complete results of their labours, the delay must in a great measure be ascribed to the pressure of their many onerous duties, and to the topographical difficulties which Spain, especially in its northern provinces, presents.

In the meantime, until a complete and detailed survey of the province shall be published, the following notes may perhaps be found useful. They have no pretensions to that exactitude of detail which must result rather from continuous special and collective observations, than from the disconnected efforts of private individuals otherwise continuously occupied.[1] We propose to arrange them under the following heads:

I. Outline sketch of the physical geography of the province.

II. Outline of the geological features of the parts of the province of Santander bounded by the bay of Santander on the east, the river Deva on the west, the main Cantabrian chain on the south, and by the sea on the north.

III. Geognostical relations of the more important metalliferous deposits.

IV. Mineralogical structure and chemical composition of the ores, with some remarks upon their mode of production.

The sketch of the physical geography being merely intended to bring before the reader's mind the more salient orographical and hydrographical features of the district, without which it would be difficult to realize its true geological character, must necessarily be very brief. The title of our paper will sufficiently indicate that we do not pretend to settle definitively the exact stratigraphical classification or age of all the rocks which occur in the district. To do so, for a country crossed by high, and often almost inaccessible mountains, would require a very close and detailed study, and far more complete collections of fossils than have yet been made. The second division of our notes must, therefore, be looked upon as only an explanatory introduction to the third and fourth ones. We believe, however, that, notwithstanding its many deficiencies, and that some of our statements may require modification hereafter, our sketch of the geological features of the province will be found to be a contribution to the previous knowledge of the district.

I. OUTLINE SKETCH OF THE PHYSICAL GEOGRAPHY OF THE PROVINCE.

The province of Santander forms part of the strip of mountainous land which constitutes the southern shore of the Bay of Biscay, and is separated from the central plateaus by the Cantabrian Mountains, or prolongation of the Pyrenees, which, under various names, traverse the north of Spain from east to west. Its eastern boundary is formed by the province of Biscaya, and its western by that of Asturias. Its width from the mountains to the Bay of Biscay is about twenty-five miles, and its length about sixty miles. The Spanish name of "La Montaña" is peculiarly appropriate, at once furnishing a very correct idea of the general topographical character of the province, while it at the same time suggests to the mind that variety and interest to which, in a geological point of view, it may fairly lay claim.

---

[1] A portion of the mineralogical observations which are contained in the following notes, have already formed the subject of a paper which was read before the Royal Irish Academy on the 11th November, 1861, and which has been published in its *Proceedings*, vol. VIII., part I., p. 5.

Mountain-chains are, in fact, the dominant physical feature of the province. The southern boundary, as already stated, rests on the portions of the Cantabrian chain, which are known by the names of Sierra Engana, Sierra de Sejos, Sierras Albas, Picos de Europa, etc. Those high peaks, which increase in elevation from the Sierras Engana and Sejos, east of Reynosa, to the confines of the province of Asturias, present peculiar outlines according to the nature of the component rock. Where sandstone predominates, the forms are more rounded and the outlines less broken, and in some cases becoming castellated, where a certain regularity of bedding and a harder and less jointed rock offered greater resistance to the denuding agencies than the neighbouring points. The peculiar colour of the landscape also deserves to be noted; the various tints of green and brown blending together, and varying in intensity according to the activity of vegetation and the greater or lesser amount of surface denudation which the rocks have undergone; the latter, in its turn, depending, to a certain extent, upon the aspect and inclination of the beds. A curious belief of the country people, which attributes the eating away of stone under atmospheric influence to its exposure to the direct rays of the moon, indicates at once the extent to which those sandstone rocks decay, and the influence which certain aspects, in which they are continuously exposed to a maximum of alternations of heat and cold, have upon their outlines.

Such physical peculiarities have, as may be supposed, a direct influence upon the habits and mode of life of the population. Nearly the whole of the centre of the province, as well as part of the country lying between the Dobra or subchain, is occupied by sandstone. The beds of this rock alternate in many parts with beds of clay and shale, which afford materials for soils, some of which are pasture lands, and others are covered with woods and copses, thus affording the rural population a supply of fuel and materials for building and furniture. Three-fourths of this sandstone region is, however, commons land, rarely presenting any extensive plains capable of calling forth the agricultural energy of the population, and serves principally as pasture for the sheep and cattle which constitute the wealth of the inhabitants. In the higher and more inaccessible ranges, some very fine forests still exist, which furnish very excellent ship-building materials, both for the military and mercantile marine. By far the most extensive and magnificent of these great forests still grows in full luxuriance, clothing the sandstone rocks, in which lies the upper valley of the river Deva, in the district of Liévana.

With fine and extensive pasture land, narrow, but fertile valleys, a comparative abundance of timber and other building materials, in a country rugged and thinly populated, and consequently presenting great natural difficulties for road making, it can easily be understood that the population must offer many of those traits of character and habits peculiar to borderers and mountaineers. Their very tools represent types, which carry us back in imagination to the time of the Romans, and yet, when attentively examined, show a degree of adaptability to the wants of the people, not always to be met with in more modern, and what, on that account, are too often considered to be more improved forms.

The remainder of the surface of the province is principally formed by limestones, some of which constitute mountain masses equally interesting, and more prominently conspicuous. More compact and resisting in texture than the sandstone, and at the same time less alternated with beds of clay and shale, and presenting a greater number of vertical dislocations and joints, they form ranges of mountains generally running east and west parallel to the coast line, and which, rising successively in elevation from the coast, determine the general physical outlines of the principal valleys. Where the beds attain a high inclination, as in the mountain ranges to the E., W., and S.W., the outlines of the mountains are highly varied and picturesque, offering many of those pointed summits so characteristic of some of the Alpine ranges, of which the Naranja de Bulnes, one of the peaks of the Europa chain, where the elevation reaches more than 2600$^{m.}$, affords a good example. Precipitous sides, deep narrow valleys, generally the beds of mountain torrents or rapid streams, and often presenting natural caverns filled with stalactites; a nearly uniform grayish white colour, due to the bareness of the rock, especially when it has a southern aspect, relieved now and then by tufts of trees, and in the higher ranges by the intense green of the live oak, whose tortuous roots adapt themselves to the rugged surface and deep narrow clefts of the rock,—such are the principal characteristics of the limestone region of the province, and which, taken in conjunction with those already described as peculiar to the sandstone districts, fully justify the title of "La Montaña".

Seven principal rivers traverse the province, all of which rise in the valleys formed by the spurs of the main chain of the Cantabrian Pyrenees. Commencing with the most westerly, they are: the Deva, the Nansa, the Besaya with its confluent the Saya, the Pas with its confluent the Pisuena, the Miera with its confluent the Riano, the Campiezo, and the Ason. In their upper courses they have all the characteristics of torrents fed by numerous streams which flow down the sides of the mountains. Their general direction is from south to north; and, owing to the great declivity of their whole beds, which traversing, as they do, a country that rises so rapidly from the sea into high mountains, their waters, carried forward with impetuosity, seem to have cut through all intervening obstacles, even the Dobra chain, nearly perpendicularly to the general direction of the latter. They have rarely formed wide valleys or alluvial plains, so valuable for agriculture, the more extensive being those of Cabazon de la Sal, Torre la Vega, and that of Renedo, immediately below Viesgo. None of the rivers are navigable except the Besaya, at Suansez, for a few miles from the sea, the Deva and the Nansa forming merely short estuaries of difficult access for shipping.

The declivity of their course, and the great facilities which present themselves of forming heads of water in the narrow lateral valleys along their courses, fit them on the other hand to be sources of immense water-power. The most remarkable are certainly the Besaya, which traverses the whole province, and along whose course run both the high road and the railway which connects the province with the south; and the Deva, which rises in one of the most productive parts of the province, the valley of Potes, and which traverses the whole eastern side of the limestone region forming the mountains of Europa, its bed lying in a valley very much encased in rocks, and in some places even escarped.

II. OUTLINE OF THE GEOLOGICAL FEATURES OF THE PARTS OF THE PROVINCE OF SANTANDER, BOUNDED BY THE BAY OF SANTANDER ON THE E., THE RIVER DEVA ON THE W., THE MAIN CANTABRIAN CHAIN ON THE S., AND BY THE SEA ON THE NORTH.

§. 1. *General lithological character of the rocks of the main chain, and description of the section* I., *Plate* 2, *corresponding to* A B *on the map of the province.*

The centre and south-western parts of the province are occupied by two groups of rocks, distinct not only in their general physical characters, in their comparative masses, but also in their superficial extent and the elevation which they attain in the principal mountain ranges.

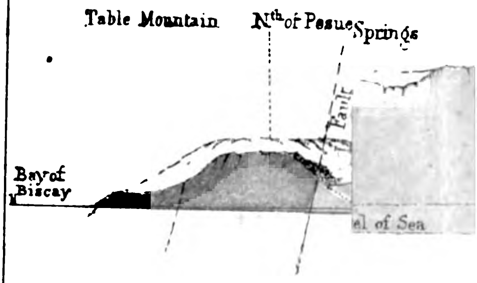
The first, by far the more massive, and constituting some of the highest peaks in the s.w. of the province, is represented principally by a limestone remarkably jagged in its outlines, hard and splintery, generally white externally where most exposed, but grayish internally, and often almost black in its lower part, being then also much shivered. In certain places where high escarpments present themselves, bands of hornstone are found. In others it has a saccharoidal texture, and becomes slightly rose coloured, and apparently dolomitic. Some very large caverns occur in those escarped surfaces, not unlike what are seen in the valley of the Meuse, and which serve as shelter for the herds of goats and mountain sheep which can alone live upon those precipitous mountain sides. Those caverns, like the Belgian ones, contain no doubt fossil bones, and are hence deserving of investigation. Many of the similar caves in the neighbouring province of Asturias do contain fossils, according to Don G. Schultz. Lesser caverns, fissures, and curious holes are also observable in this rock, and are distinguishable from similar appearances in the newer rocks by the apparent absence of any traces of bedding which might account for their formation.

At its base this limestone seems to be associated with a hard gray sandstone rock; and both rest unconformably upon thick beds of slate clay, generally dark-coloured, though occasionally reddish. Beds of conglomerate, formed principally of quartz pebbles, with an extremely hard silicious cement, surpassing in that respect the sandstone, appear to be also associated with those slate clay beds. The limestone rocks are very much upheaved, the beds being often nearly vertical, and forming a succession of anticlinals whose general strike may be taken as E. a few degrees N., as in the neighbouring province of Asturias.

The second group of rocks consists of beds of variegated clays, alternating with soft sandstones, beds of slaty clay, thin beds of marly limestone of a dark gray colour, alternating with thin layers of black marly clay. The predominating colour of the sandstones is red, the colour becoming more intense in the lower beds, the texture of which is also more compact, and the beds thicker.

The limestone rocks upon which the beds of clay, sandstone, etc., rest near the Deva, rise to the south and south-west into the lofty mountains of the Picos de Europa and other ranges, whose jagged peaks, picturesque but inaccessible escarpments, and deep gorges, characterise the higher ranges of the Cantabrian chain.

The remaining portion of the province forms a belt of about $8^{\text{km.}}$ to $10^{\text{km.}}$ wide, and is the most accessible. Being most distant from the axis of the Cantabrian chain, the mountain ridges,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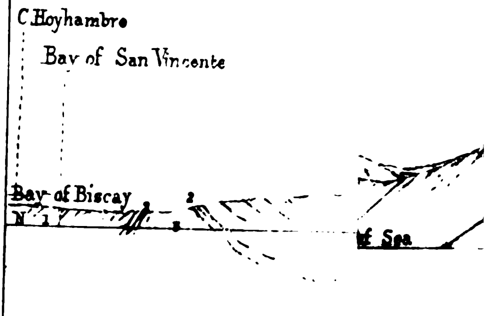
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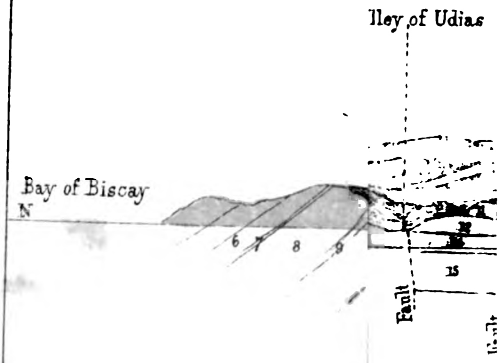
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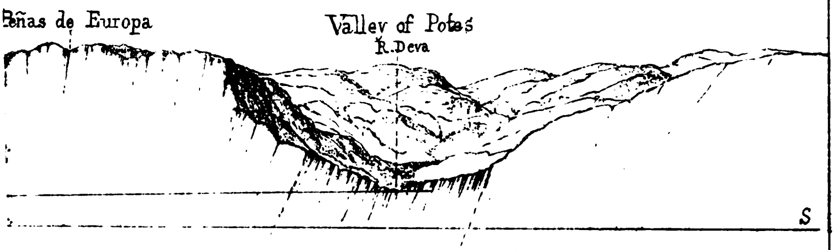
Plate 2.


Peñas de Europa
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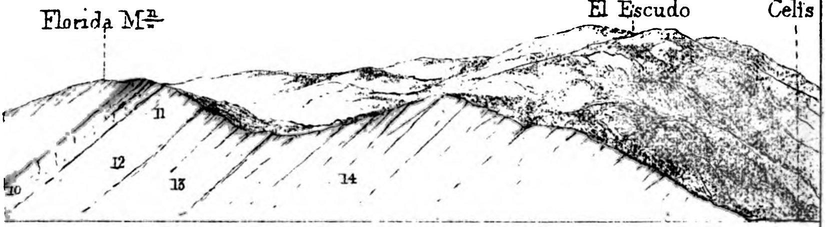
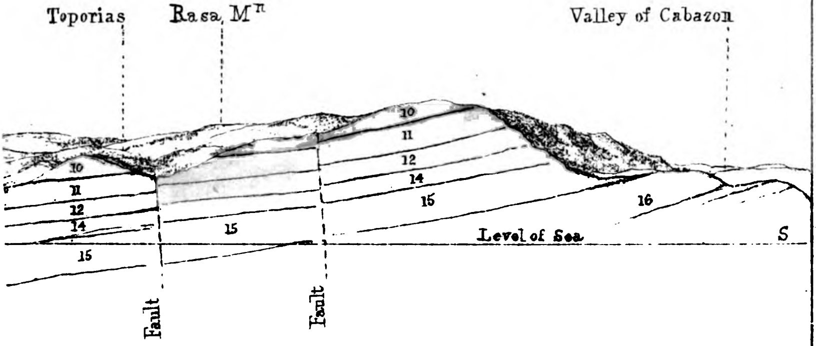

Florida Mn
El Escudo
Celis


Toporias
Rasa Mn
Valley of Cabazon
Level of Sea
S
Fault
Fault

which, as already mentioned, generally run E. and W., have there less elevation, and present greater facilities of access, and less irregularity in the stratification of their component beds. The Dobra range, which may be looked upon as the southern boundary of this belt, is cut perpendicularly by several of the principal rivers which water the province, the Deva, the Nansa, the Besaya, and its confluent the Saya, etc. Thus the valleys of those rivers offer a series of excellent natural sections, so that by following either of the latter to its point of junction with the range in question, and carefully examining the lofty and precipitous rocks which overhang and close in their torrential beds, the peculiar geognostical features of the different formations may be studied. We propose first to study those sections in detail, and then to summarize the conclusions which may be drawn from their study respecting the geological relations of the rocks of this belt, which to a certain extent may be looked upon as the key of those of the whole province.

The most natural order in which to study our sections will obviously be, to begin at that one which traverses chiefly the oldest rocks. We shall accordingly commence with that afforded by the valley of the Deva. This order will present the additional advantage of illustrating, by the description of the rocks occurring along the section, what we have just said concerning the rocks of the main chain.

The coast at the mouth of the Deva is formed by a hard white quartzose sandstone, which is a continuation of those remarkable high platforms formed by alternations of hard limestone and quartzose sandstone, which give such a peculiar character to the Asturian coast, and which will be fully described at p. 46. This sandstone is in contact with nummulitic beds from near Pesues westward to Columbres beyond the Deva. The nummulitic series is particularly remarkable between Unquiera and Pesues, on account of the high dip of the beds, their great mass, and their relation to the platform just alluded to. It consists of the usual limestone containing *Conoclypus conoïdeus*, Ag., *Ostrea latissima*, Desh., *Serpula spirulæa*, Sow., etc., yellow sand and sandstone. To the south these beds rest upon the usual succession of cretaceous rocks.

To the south of Columbres limestone rocks, hitherto considered to be carboniferous, rise into a considerable mountain, having an elevation of about 350$^{m.}$ to 400$^{m.}$ at least, and forming part of the east and west range called the Sierra de Cuera. On the south of this mountain, and near its summit, is situated the village of Alevia. Here the limestone, which dips to the north at an angle varying from 40° to 45°, forms a bold and precipitous declivity towards the valley. This limestone is nearly black, and seemingly much fractured, the joints being filled up with a rose coloured calc spar. The colour of the spar may be due to the neighbourhood of a bed of manganese which occurs nearly at the top of the mountain, and which, from its strike being east and west, and its dip about the same as that of the beds of enclosing rocks, may be contemporaneous. The ore would seem to have been chiefly manganite. This circumstance, joined to the almost inaccessible position of the mine, defying all attempts at road-making, and leaving no other method of transport practicable but the shoulders of the vigorous inhabitants of the village, contributed to render the works unprofitable.

According to Don G. Schultz, another patch of cretaceous rocks occurs in the valley to the south of Alevia, but we have had no opportunity of examining the locality, nor have we any reliable data as to their precise nature. It is certain, however, that beds of limestone containing numerous fossils, and nearly vertical, occur near the eastern extremity of this valley, the high road which leads to Unquiera being cut in their vertical beds. The rock in question is of a dark grayish-blue internally; a thin zone of about one inch thick, of a somewhat brownish colour, evidently due to weathering, being found at each side of the several beds. The texture is saccharoidal, and in that respect is very similar to that of certain limestones found in the neighbourhood of the principal dolomite bed of the province, while, on the other hand, it is quite distinct from that of the great limestone mass already described.

Following the line indicated on the section, and traversing the valley in which the Deva flows, bending towards the east for about a mile, and then returning to the direction of its former course, the first crests of the lower ranges of the Peñas de Europa are met with. The stratification may be still observed, having the same general strike, but a higher dip than at Alevia. Those nearly inaccessible mountains, which present an extremely uneven surface, generally clothed with trees peculiar to those high ranges, rise continuously in elevation up to Tresviso, to the south of which a very deep and narrow valley occurs, running east and west, and forming a bed for a wild mountain torrent, fed by the melting snow of the Europa chain. Between the point of junction of this stream with the Deva and the valley of Alevia, the underlying hard gray sandstone presents itself on both sides of the bed of the river Deva, apparently forming an anticlinal axis, as indicated in the section. About one mile to the south of this point of junction, and consequently higher up the course of the river, occur the hot springs of La Hermida, of which mention will be made hereafter. Here the dip of the limestone can scarcely be determined, the bedding being still less marked. The colour becomes darker in that part which overhangs the Deva, and still more so near its contact with the beds of shale in the valley of Potes; bands of black limestone are also frequent in it.

The line of section passes over the Peñas de Europa, which form the highest peaks in the province, attaining, as already mentioned, an elevation of 2600^{m}, and whose mines of calamine, blende, and galena are extremely interesting. The limestone here presents the same general aspect as in the lower ranges, but becomes whiter and more marble like, and is also much more highly fissured. On the north side of the valley of Potes the limestone beds are almost vertical, inclining about 10°–12° to the north; they form as it were an immense wall, so bold and clear is their outline, and so precipitous their declivity. Immediately underlying the limestone are found beds of hard shale and clay, out of which the valley of Potes has been eroded; these beds are also nearly vertical. Associated with these shales in the inferior beds are found quartz conglomerates, derived no doubt from the denudation of the gray sandstone or quartzite-like rock which underlies conformably the shale and clay just described, and in which are found veins of copper associated with veins of quartz, as will be more fully indicated in the description of the mines of Pico Jano.

§. 2. *Description of Section* II., *Pl.* 2, *corresponding to Section* CD *of the map.*

We have already mentioned that between San Vicente de la Barquera and the Asturian border village of Columbres, is found a considerable development of nummulitic beds. These are indicated in the cross section I., Pl. 2, which is marked on the map by the line CD, which passes through San Vicente. The dip of these nummulitic beds is about 20° to 25° N., passing under the newer formation situated between its outcrop and the sea, and disappearing apparently in the direction of Cabiedez, near a village called Roiz, under the overlying rocks. The estuary which runs by San Vicente, and which receives a mountain stream near the point called Peña Candil, about three miles south from the coast, has cut through the bed, and thus laid bare a section on each side. Near the point of junction just mentioned, a very fine specimen of *Hemipneustes radiatus*, Ag., was found, which the action of the stream had left *in situ*, the enclosing marly limestone having been eaten away. Between this point and that more to the south, where the beds constituting the

Florida mountain crop out, the dip of the strata varies from that already described, tending to become horizontal, and even apparently to incline towards the south, and then rising again, so that the beds present anew their original dip to the north. There is thus naturally formed a synclinal trough, slightly marked in the lower beds, but quite recognizable in the upper ones of sandstone, their castellated outlines forming conspicuous objects, when viewed either from the valley on the north side of the synclinal axis, or from that to the south. It is this irregularity in the continuity of the dip of the strata which brings the underlying beds, characterised by the abundance of *Micraster coranguinum*, Ag., to the surface as well to the north as to the south in front of the Florida mountain, and also the overlying beds of sandstone, and the thick underlying beds of greenish sandstone and ochreous clay. From under these, limestone beds come out with a dip of 40° to 45°, and form the Florida mountain, in which a remarkable mass of dolomite occurs, which will be more fully described when we come to the description of the Florida mines; the mountain itself has an elevation of about 550$^{m.}$ to 600$^{m.}$ above the sea. The dolomite crops out near the south side of the crest of the mountain, and rests conformably on beds of limestone. Immediately underlying the limestone are found beds of shales and clay, which form the bottom of a deep narrow valley that separates the Florida from the Escudo mountain, where terminates the section, and which consists of the red sandstone beds hereafter to be described, as occupying the interval between the beds of Mercadal and the limestone of the Dobra range (Sect. IV. Pl. 3).

Between the Escudo mountain, which rises to an elevation of about 700$^{m.}$, and the underlying Dobra limestone formation, intervenes a valley in which is situated the village of Celis, not far from the junction of the sandstone and limestone. Very large crystals of quartz are found here, some being clouded, and others perfectly transparent. This is perhaps the only place in the province where transparent crystals occur, although quartz crystals with other peculiarities are elsewhere abundant, and will be noticed in connection with the limestone of the Dobra range.

The beds of nummulitic limestone above described as sinking near Roiz, rise again to the surface with a north-east strike, and, in conjunction with other rocks of the same age, seem to form the headland called Cape Hoyambre, which lies between San Vicente de la Barquera and the Rabia stream, to the westward of which they run out into the sea towards the north-east, forming a very remarkable reef about a mile and a half in length, well known to the fishermen of the coast, on account of the safe anchorage which they find behind this natural mole during the north-west gales. Apparently they do not again reappear along the coast, not being recognizable at Comillas, nor yet still farther to the east, where the transverse section FG (on the Map, sect. III., Pl. 2) is supposed to be taken. If we suppose a plane of section to pass through the beds forming the eastern side of the bay of San Vicente, at about $1^{km.}$ from the last described section, and parallel to it, we have the following succession of beds:—

1. Beds of limestone dipping N. 45° or 50°, forming the great mass of the Cape Hoyambre, which bounds the bay on the E. They apparently correspond to the beds upon which is built the Castle of San Vicente, and in which *Orbitolinas* are very abundant.
2. A thin bed of dolomitic limestone, less brown and more rosy or pink, as also more compact, than that of Comillas. It forms a bold escarpment on the road to San Vicente, near its junction with the old road *del Tejo.* This rock appears to form a part of the next series of beds.
3. Red ochry clay, very plastic, and consequently producing very good tiles and bricks. Some beds are almost white, others blue and mixed with gypsum, which is generally transparent, and also with grains of quartz. A bed (or beds) of a red conglomerate, formed of pebbles of quartz, cemented by carbonate of lime, occurs here also, fragments of which exist as large boulders on the strand between Cape Hoyambre and San Vicente, forming very conspicuous objects. Some other rocks, chiefly limestone and alternating with dark gray marls in which lignite has been repeatedly found, intervene between the ochry clays and the nummulitic limestone No. 4.
4. Nummulitic limestone, the dip of which is somewhat lower than that of the clay beds No. 3, and containing *Hemipneustes radiatus*, Ag.
5. Sandstone in immediate contact with the nummulitic beds; some of them, particularly in the lower portion of the group, are coarse grained, almost conglomerates, and nearly white in colour.
6. Marly limestone, full of fossils, *Micraster coranguinum*, Ag., being extremely abundant.
7. Thick beds of limestone, generally presenting a grayish colour, a sub-crystalline or dolomitic grain, distinct however from what is known as saccharoidal. The outside of the beds is generally weathered, the colour there changing and becoming brownish gray. Intercalated beds of marly black clay also occur.
8. Beds of ochry sandstones and clay, one of which is black and slaty, being also highly impregnated with iron pyrites.
9. Thick beds of limestone, some of which near the base of the group are very marly, of a grayish, black colour, apparently hydraulic in their character, and containing large oysters imbedded in the mass.
10. Principal bed of dolomite, consisting of a bed of brownish gray

crystalline rock, extremely hard, very cellular, and presenting but few traces of stratification in its interior mass. The weathered surfaces show them however perfectly, as also the concordance of this stratification with that of the overlying and underlying rocks.
11. Secondary bed of dolomite, quite similar in texture and general characters to No. 10, from which it is separated by about 50$^{m.}$ thick of limestone. It is quite irregular and almost insignificant in thickness, as compared to that of the principal bed.
12. Limestones of a grayish colour, tinged with iron, very loose in their texture, but hard and alternating with beds of marly clay.
13. Brownish clays alternating with thin beds of limestone.
14. Red sandstone of the Escudo mountain.

The beds Nos. 2 and 3 line the south side of the bay of San Vicente, enter the harbour, and form the south-western shore, upon which the principal part of the town has been built. The ease with which they may be eroded would account for the formation of the *Ria*, or estuary, which constitutes this harbour. On this s.w. shore formerly existed a large boulder of the dolomite, some ten or twelve cubic metres in volume. At the point where the nummulitic limestone crops out on the south-east side of the *Ria* of San Vicente, about 2$^{km.}$50 from the principal bridge, beds of dolomite with traces of calamine and galena occur. This dolomite is probably identical with No. 2 in the above table, its reappearance being explained by supposing a synclinal valley extending between this point and the sea-shore. The succession may, however, be perfectly regular, in which case we should assume the existence of two beds of dolomite. In either case the occurrence of dolomite here is very interesting, because, firstly, it probably belongs to the tertiary formation, and secondly, from its containing calamine, which would thus be proved to have been deposited during that epoch. In a subsequent part we shall have more to say on this subject. In placing it, however, in the tertiary formation, we do not consider its position as definitely settled, for a closer examination may show that it is really a continuation of the dolomite of Comillas. The existence of beds of dolomite on the heights between the Rabia and the *Ria* of San Vicente, near the village of *El Tejo*, while favouring this latter point of view, does not at all preclude the former.

§. 3. *Description of Section* III., *Pl.* 2, *corresponding to Section* FG *on Map, and* AB, *Pl.* 5.

The plane of this section traverses the valley of Comillas between Tramalon and the valley of Ruyloba, though closer to the first-named point. All along the trough of this valley, which extends from the mountain stream La Rabia one and a half miles to the west of Comillas, to Tramalon, about two and a half to three miles to the east, the dolomite presents itself continuously, forming a very distinct anticlinal, and bounded on both sides by limestone beds whose upheaval and subsequent denudation have left it bare (see Plate 4). The dips of the limestone on the north and south sides are variable, being generally highest on the north, along which abundant fossils may be collected, particularly in the neighbourhood of Venta la Vega, about three quarters of a mile east of Comillas.

In the limestone indicated on the section as immediately overlying the dolomite, are found in great abundance *Orbitolina concava*, Lam., *Rhynchonella depressa*, d'Orb., and *Terebratula Menardi*, Lam. Upon those beds, and towards the sea, rest conformably a thick series of soft green sandstone beds; upon those rest limestone beds, of which a more detailed description will be given further on. Those beds rise about 100$^{m.}$ above the level of the sea, forming a hilly chain along the north of the valley. The dolomite exposed here is about 250$^{m.}$ to 300$^{m.}$ in breadth; it is partially covered over by the highly ochreous earth which constitutes the soil: portions of it, however, stand out here and there, of a deep brown colour and a rugged and weather-beaten appearance, which is eminently characteristic of the dolomite throughout the province. Its stratification is here nearly horizontal, but it dips away to the north and south at the junction with the limestone. This has many deep narrow fissures, some being mere joints, but others are of a sufficient width to have admitted of being subsequently filled up by infiltration from the overlying soil. Traces of calamine and blende are found near the middle, forming a continuation of the Venta metalliferous lode. The dolomite on the south side dips gently to the south, and apparently comes up again in the valley of Pelurgo, a little to the north of that of Udias. The limestone beds which overlie it, and whose stratification near the valley of Comillas varies little from the horizontal, dip, however, to the south, while in that of Pelurgo they dip slightly to the north. In these beds at Ruyloba have been found the fossils.

The beds just described are covered conformably by greenish sandstone (indicated in section III. of Pl. 2 by No. 8, and by the letters *s. s.* of Pl. 4, the sandstone here not being tinted). Between the valley of Pelurgo and that of Udias lies the range of hills forming the northern side of the latter, as shown in the section, and more fully in Plates 11, 12, and 13. In Pl. 13, a section (*a*) of the valley indicating the stratigraphical succession of the beds, shows the sandstone and limestone rocks above described overlying the dolomite. The sandstone, however, has been partially eroded, and is only exposed on some of the hills.

Underneath the dolomite, a shelly limestone comes out on the north side of the valley, in which large oysters occur abundantly; the lower bed yields also a fine hydraulic cement, of a peculiarly beautiful cream colour after it has set. The fossil oysters are likewise found in this bed, but not so frequently as in the upper beds. In preparing the cement they are carefully separated, as their presence is injurious to its quality, no doubt because they are almost pure carbonate of lime. A similar bed is found well developed likewise at Novales and Ciguenza, underlying the dolomite. A series of beds of friable sandstone and clay crops out from beneath this limestone; particles of mica are frequent in them, and they seem to have furnished a certain portion of the detritus found in the joints of the underlying limestone. Some of the lower clay beds contain abundant fossils, of which we have not, however, any specimens. In one of the limestone beds immediately in contact with them, corals of a jurassic character have been found covering several metres square on the rise of the old road between the Esmeralda and San Bartolome mines.

A very shelly limestone crops out from under the beds just described. It is the lowest of the series of limestone rocks on the north side of the valley, and is characterised by its frequent fissures, the fineness of its grain, and a gray colour, similar to that of many lithographic stones; it contains abundance of fossils, especially at the San Bartolome mine (situate in the upper part of this bed, although erroneously marked in Pl. 13, as occurring in the upper limestone). A beautiful section of the *Nerinæa Goodhallii*, Sow., has been found here, as well as a species of *Gryphæa*, which has all the characters of the *Gryphæa arcuata* of Lamarck. The frequent occurrence of this lower lias fossil here is singular.

The bottom of the valley lies upon beds of red sandstone clay and gypsum, which form the greater part of the elevated ground rising to the west of the valley of Udias, and which, covered with forest trees, is known as the Monte Corona. On the north side of the valley flows a stream which passes under the hills closing in the eastern side, and which, apparently following the strike of some principal fault or joint, as indicated in Plate 13, comes out again in the valley of Novales before falling into the sea. That a fault exists near the bed of the stream is evident from the relative positions of the rocks on the north and south sides of the valley: the limestone which immediately underlies the dolomite on the north side cropping out far above the level of the stream, while on the south side it is found on a level with it, forming indeed its bank. There is here, however, an apparent mingling of the dolomite with the limestone, whether it be merely superficial and to be accounted for by chemical metamorphosis or other local action, or peculiar to this part of the formation, there is no evidence to determine. In the lower part of this rock, although about 25$^{m.}$ to 30$^{m.}$ above the level of the stream, beds of the dull blackish limestone, noticed already as belonging to the northern side, and as furnishing a highly hydraulic cement, may be recognized. The rock here contains hydrocarbonate of zinc, and in it have been found the cave and fossil bones, of which a fuller description will be given when describing the Dolores mine.

The stratification is here nearly horizontal, while on the northern side, where the stratigraphical succession is most marked, the inclination of the beds increases proportionately to their elevation, as is shown by section *a*, Pl. 13.

The dolomite is here highly fissured, and contains several extensive mines of red calamine, blende, and galena, the principal one being that known as the Angel de Toporias, the works of which pass under the overlying limestone, thus connecting the great mineral deposit found in the dolomite which crops out in the valley of Toporias, with that found in the south side of the valley of Udias. In the hill which bounds this side several faults occur, running generally east and west, and throwing up successively the beds which crop out to the south, over those marked red sandstone and schiste, and which form the north side of the valley of Cabazon de la Sal, while the lower beds of the latter series seem to form the level plain which here intervenes between the river Saya on the north side and the Dobra chain on the south, where the same characteristics present themselves as already described in the details of the preceding section.

Reference has been made at the beginning of the section to the rocks in immediate contact with the Venta mine, where they present peculiarities requiring especial notice. The dolomite at this point is thrown up nearly vertical, as may be seen from the transverse section AB, Pl. 5. The limestone beds on both sides of the valley are also nearly vertical, dipping south. An attentive examination of the relative positions of those beds at different points between the extreme limits of the valley, would lead us to conclude that the bed of dolomite was here so contorted that it formed almost a loop, which, after the denudation of the top, left the parts of the bed forming the anticlinal with apparently the same dip to the south. In Pl. 7 will be found a diagram, in which an attempt has been made to demonstrate by outline sections at different points of the valley, that the dolomite is really inferior in age to the limestone which bounds it to the north and to the south. The outlines 2 and 3 show that this is really the case, while, if we judged by the outline shown by No. 1 alone, we should conclude that the dolomite is posterior to the limestone on the south, but anterior to that on the north, which it seems to overlie conformably. The first two sections in Pl. 6, the planes of which are supposed to pass at two points one quarter of a mile distant from each other, and to the west of the village of Comillas, tend also to prove that the dolomite is anterior. The faults running east and west, and quite recognizable in the neighbouring cliff, which forms the eastern side of Comillas Bay, would have rendered the exact determination of the relative positions of the beds somewhat difficult, were it not for the evidence presented by the cross sections at different other points of the valley. Assuming, then, that the rocks to the north really overlie the dolomite, the age of the former may to a certain extent be determined by the fossils found abundantly in them. Among them may be mentioned *Neithea quinquecostatus*, Br., *Ostrea carinata*, Sow., *Exogyra haliotoidea*, Goldf., *Caprina adversa*, d'Orb., *Terebratula sella*, Sow., *T. Menardi*, Lam., *Trigonia dædalia*, Parks., and many casts of other species of *Ostrea*, *Pecten*, *Turrillites*, etc.

In order to complete the tabular statement of the succession of rocks as in the former section, it is necessary to describe in some detail the phenomena which are presented by the harbour of Comillas. As has been mentioned above, and as will be seen by the plan of the mines of Comillas (*Pl.* 5), the valley of Comillas, which runs E. and W., is bounded on both sides by limestone rocks, while its trough is occupied by dolomite. These limestone rocks on the north form, as it were, a great dyke which separates it from the sea, and are cut through by the creek forming the mouth of a small stream, which here runs into the bay after having traversed the narrow valley lying between the bridge called Puente Portillo and Peña Castillo, its general direction being N. and S.

The south-west shore of the bay presents the following succession of rocks:—

1. Limestone beds which form a reef of rocks running out towards the N.E., almost completely covered at high water, and full of fossils, but which are so bound together by sparry limestone, into which many of them are converted, that it would be almost impossible to separate them from the corals which are extremely abundant in those rocks.
2. A bed, which is here very thin, though apparently much thicker where it crops out on the headland forming the N.W. side of the harbour, and composed of dark gray nodules mixed up with, or bound together by, an earthy paste of the same colour, apparently very marly.

3. Beds of greenish sandstone somewhat loose in its structure, but presenting no traces of fossils.
4. A bed of marly clay mixed up with nodular limestone, and abounding in fossils, principally oysters, trigonias, etc. This bed comes out also to the south of the Venta mine in the limestone immediately overlying the dolomite.
5. Limestone, to the south of which, and in its immediate contact, comes out the dolomite forming the bottom of the valley.

At the point of the coast where the plane of section is supposed to intersect it, the shore would be formed by the limestone No. 1, and the succession of rocks just given would be found to occur between the shore and the point where the dolomite would first appear. Accordingly, the cliffs along the eastern side of the Bay of Comillas, which rise about 35$^{m.}$ to 40$^{m.}$ above the sea, present us with a series of contorted beds belonging to the limestone No. 1, intersected by faults, accompanied by displacements, and containing fossils (*Neithea quinquecostatus*, Br., *Ostrea carinata*, Sow.), and abundant casts of *Pectens*, *Nerineas*, *Ostreas*, etc.

The bed No. 2 is not visible, but the sandstone No. 3 appears in the S.E. angle of the bay, so that the eastern side is formed by the beds 1 and 3. The latter is, however, but slightly developed, comparatively to what it is at Comillas, along the south-western shore, and at Tramalon. It is like a wedge between the limestones 1 and 5. There is evidently a fault here, accompanied by a downthrow which is undoubtedly the cause of the disappearance of the beds 2 and 4.

The shore a little beyond the harbour on the western side offers a section of another set of beds, resting directly upon the limestone No. 1, which rises here, as we have said when describing the rocks of the south shore, from the level of the sea, beneath which it dips with a gentle inclination towards the N.E., while on the eastern shore the same rocks are thrown up, as we have mentioned, 35$^{m.}$ to 40$^{m.}$ The beds in question are therefore posterior to the limestone No. 1, and must have been denuded from that rock on the eastern side, and the Bay of Comillas in part formed by their erosion. In giving the succession of beds along the plane of section, it will be better to begin with those beds, and thus render the series more complete, although the point at which they occur is situated from 1½ to 2$^{km.}$ west of the plane of section.

1. Series of beds of soft slightly greenish sandstone, when not stained by oxide of iron, about 8$^{m.}$ thick. The lower beds immediately in contact with No. 2 dip slightly to the N.E., but the upper beds are almost horizontal. The planes of bedding are very close,

whilst the planes of jointing are very marked and have principally contributed to the destruction of the promontory which existed formerly to the N.W. of the harbour, where a small block of this rock still exists. No fossils have been found in it.

2. Black shaly clay $1^{m}\cdot50$ thick, highly impregnated with pyrites. It is somewhat carbonaceous, like the indurated clay beds which accompany beds of coal. By the decomposition of the pyrites, efflorescences of alum, sulphate of alumina, etc., are continually being formed. The joints which traverse the sandstone No. 1 are common to this and the following beds.
3. Very hard brown or gray limestone, $1^{m}\cdot50$ in thickness, intimately connected with the underlying sandstone, into which it seems actually to pass, no apparent plane of bedding existing between them. This limestone has the same fissile structure as the sandstone, and in certain places has actually become decomposed, leaving a brown earthy skeleton which retains the original jointing. This is evidently a calcareous sandstone, more or less argillaceous, formed by the infiltration of carbonate of lime into one of the upper beds of No. 4.
4. Greenish, and in some points gray sandstone, slightly micaceous, somewhat more compact than No. 1, $3^{m}\cdot80$ thick. In this bed have been found pieces of amber, although small, and also traces of fossil plants, apparently marine. The planes of bedding have ripple marks.
5. Beds of shaley, pyritic clays, $2^{m}\cdot0$, thick, very similar to No. 2, but containing thin sandstone plates bearing the imprints of ripple marks.
6. Hard shelly limestone (the No. 1 limestone described above as coming out at the N.W. and N.E. of the Bay of Comillas).
7. Bed of clay containing dark gray nodules (No. 2 of the series of the Bay of Comillas).
8. Sandstone (No. 3 of the series of the Bay of Comillas).
9. Thin beds of marly clay containing nodular limestone, and abounding in fossils (oysters, trigonias, etc.).
10. Limestone beds of dark gray colour, the planes of stratification being generally marked by thin layers of black marly clay, and containing *Orbitolina concava*, Lam., *Rhynchonella depressa*, d'Orb., and *Terebratula Menardi*, Lam.
11. Hard and brownish-gray crystalline dolomite which comes out in the valley of Pelurgo, and is the same as that of Udias, Ruyloba, and Novales.
12. Limestone immediately underlying the dolomite, and in which the mines Esmeralda and Magdalena of the Udias district occur. Its colour is generally dull gray in the interior, though somewhat more white exteriorly; the texture is not at all crystalline. In some points it presents compact beds of large oysters.
13. Beds of hydraulic cement limestone, forming the base of No. 12; they are shown in section *(a)* Pl. 13. Those beds come out most

prominently at Peña Castillo, where they have been worked for the cement. In their clefts is deposited the ore of the Magdalena. Most of the beds crumble away by exposure to the atmosphere. This rock presents also the peculiarity of joints filled up with a conglomerate of sparry limestone, coloured with iron, and cementing nodules of brown hæmatite in great abundance. One of those joints or dykes occurs at the s.w. point of Peña Castillo.

14. Beds of slate, clay, and greenish sandstone, often very micaceous.
15. Great beds of limestone, in which occur the mines San Bartolome and San Roque. It is very much broken by jointing and cavities, a remarkable one of which occurs at the foot of the San Bartolome mine. The colour is generally light gray, approaching very much that of lithographic limestone, the texture of which may be said to be almost that of nearly the whole group. Its fracture is generally conchoidal, and presents abundant fossils completely replaced by calc spar, and belonging apparently to *Gryphæa arcuata*, Lam.
16. Red marly clays and sandstones, which form the hills between Toporias and the valley of Cabazon de la Sal. Beds of limestone also occur in this valley, but are of inferior importance compared to the clays and sandstones.

In the section III., Pl. 2, the rocks 1 to 5 are not of course shown, because, as before observed, they do not occur to the E. of Comillas Bay. The section commences therefore at No. 6. At the point where the plane of section passes, as is shown in III., Pl. 2, the beds between the valley and the sea dip highly to the N. See also the sections of the valley of Comillas, quarter of a mile and half a mile E. of the village (Pl. 6). But on the W. shore of the Bay of Comillas itself the limestone overlying the dolomite, the latter rock, and the underlying limestone, appear all three to dip to the south, by which the relative positions of the beds are reversed, as is shown in section A, Pl. 5, and by the diagram Pl. 7. Those changes of dips have an interesting relation to the mineral deposits of the Venta mine. It was probably produced by an upheaval to the S.E. in the mountains, accompanied by a subsidence to the N.E. along the sea, resulting in a series of S.E. and N.W. faults, converging towards Comillas. As the maximum of elevation and of depression would form the base of a triangle, the minimum of both would be at the apex. If the two forces were not equal, a fold or sharp anticlinical would be formed, which towards the apex would reverse the dips in the space of a few hundred metres. The dolomite must have had a fissure produced along the strike of its anticlinal, and such we find to have been the case along the Valley of Comillas, which joint became afterwards mineralized, as we shall see in the sections of the mines of Comillas.

Between the valley of Comillas and that of Pelurgo the beds still dip to the N., but at a moderate angle. Such is also the case in the mountain which separates the valley of Pelurgo from that of Udias. In the axis of the latter valley a fault occurs, such as should result from the action of an elevating force to the S., as above described. This fault was accompanied by an upthrow on the south side of the valley, as is indicated on the section we are describing in the plan of the valley of Udias, Pl. 11, in the view of the two sides of the valley in Pl. 12, and in section *a*, Pl. 13. This upthrow is of considerable importance in connection with the succession of beds which the section we shall next describe presents. In describing the mines of the valley of Udias we shall have much more to say upon this fault. Not only does the position of the beds at opposite sides of the valley prove the existence of the fault, but we have evidence of the existence of several other dislocations, notably in the case of the stream which flows through the valley of Udias, and which disappears in a great joint of the limestone, wide enough to be followed for several yards, and reappears again in the valley of Novales, at a distance of about $3^{km.}$ from the point of its disappearance. This fault would be vertical, or at least at a high angle, to the plane of the one which produced the upthrow of the southern beds.

The same fault of the valley of Udias is interesting in connection with the question of the formation of river valleys in this and the neighbouring province of the Asturias. The origin of river valleys may be attributed to the action of two distinct classes of causes: 1. The upheaval or sinking of a part of a district, by which faults and dislocations would be produced, or a series of contortions giving rise to synclinal troughs. 2. Erosion, or the gradual wearing away of the surface of the land by tidal currents, the drainage of a district of country by rivers, and in general the wearing action of air and water. Before attention was fully directed to the magnitude of the effects which the continuous though slow action of water as a dynamic agent is capable of producing, all great river valleys were believed to be the result of the first class of causes, the second being considered to be capable of producing at most the small valleys of mountain streams. Now, however, there is a reaction; and the direct agency of upheaval, sinking, faulting, and contortions is to a great extent discarded, and the whole formation of river valleys is by some assigned to erosion, or, more strictly, unequal denudation of the surface by the sea, on the one hand, and the flow of rivers on the other. While fully admitting the adequacy of erosion to produce the greatest river valleys, and the actual production of the majority of them by that agency exclusively, it appears to us illogical to reject altogether the direct action of the first class of causes. The first direction of a river valley may have been given by a line of fault or by the axis of a synclinal trough, which subsequent erosion widened and deepened.

It is usually admitted that the chief mass of the Pyrenees was elevated during the eocene period, because we find the nummulitic beds on the coast thrown up at a very high angle, and that they have been subjected to the same disturbances as the cretaceous rocks upon which they rest, and which, as is well known, have been lifted up to a height of several thousand feet. The Cantabrian Pyrenees, including all the smaller sub-chains, have a general east and west direction, that is, parallel to the sea, while the river valleys in the provinces of Santander and the Asturias have a general direction of north and south. An upheaval on so gigantic a scale could scarcely take place without a considerable number of fractures and dislocations, and especially when this upheaval took place in a comparatively short geological period of time. Both provinces afford us numerous and striking examples of such dislocations.

We have already described the general physical features of the province of Santander, and we shall merely add that those of the Asturias are still more characteristic and impressive. The last retreat of the Celtiberians against the invasion of Roman power, the last and sole impenetrable bulwark of their descendants against the overwhelming power of the invading Moors, the province of the Asturias may be termed the Switzerland of Spain. The rocks which occupy its rugged surface belong chiefly to the Silurian, Devonian, and carboniferous formations; their hardness is generally very great, their dip high, and the river courses which traverse them are very highly encased, extremely torrential, and in no case really navigable. Abundant evidence exists of erosion on a grand scale, such as the "swallow holes", or natural shafts, in which whole rivers are engulphed; caverns of great extent and through some of which rivers flow; precipices of immense height (200$^{m.}$ to 300$^{m.}$); and, finally, great landslips such as the *fanas* or *freitas*, which Don G. Schultz describes to be "natural and constant landslips which occur in certain localities where the rock is so shivered and crumbling as not to be able to sustain its own weight on the highly inclined mountain sides, and where their loose structure being acted upon by infiltrating waters, peculiar to the surface ground, a portion of the mountain side has been brought down. The gap thus opened continues to increase little by little, extending itself from the foot of the mountain to the top, its appearance being most imposing on account of the whiteness of the sandstone and the absence of all earth and vegetation".[2]

An extraordinary example of this phenomenon occurs on the western side of the Sierra del Palo, near the village of Montefurado, in the conscription of Allande, where it is called *La Freita de Feitarbon.* In other localities such accidents in the quartzite mountains receive the general name of *Fana*, particularly where the landslip is very great, such as in the case of the *Fana de Genestaza*, 12km. south of Tineo. The first slip occurred here at the end of the last century, and has been ever since continuously increasing during the rainy season, being now the greatest and most impressive phenomenon of this kind in the Asturias. It must, in time, ultimately cut through the lofty Sierra de la Cabra, in which it will thus leave a deep gap. On the western side the landslip has already penetrated to the extent of half the breadth of the mountain, tinging with its white sands during the rainy season the waters of the river Genestaza, which flows at its foot. If, for a moment, we anticipate this result, and suppose the gap to be opened, may we not infer that the river, which now passes at the foot of the mountain, carrying away the detritus produced by the yielding rock, and thus favouring the continuation of the destructive agencies, will then flow through the entirely opened gap?

The *Fana de Genestaza* appears to afford one solution to a very difficult problem, namely, why rivers, instead of flowing through open plains or valleys, enter narrow and deep valleys, termed locally "*escobios*". In some of those which traverse quartzite and slate rocks in the Asturias, the escarpments are so great that in one case—the Návia—the borders of a portion of the river present neither "roads or villages, industry or traffic".[3] The Narcea furnishes another example of the same kind; whole sections of its course being completely incapable of transit by the most daring huntsman, and even in a large open valley lying between Longrei and Paredes, in which it flows for a certain distance, it suddenly turns back towards the S.E., passes through a deep and crooked gap in the neighbouring mountain, instead of following the apparently more natural bed of the open valley. It again turns back towards the S.E. in the open valley of Paredes, and penetrating, as it were, into the mountain chain, it traverses a wild and highly escarped pass, whose rugged sides consist of the very hardest and most resisting rocks, leaving thus between Paredes and Briebes, a little to the N.W. of the point in question,

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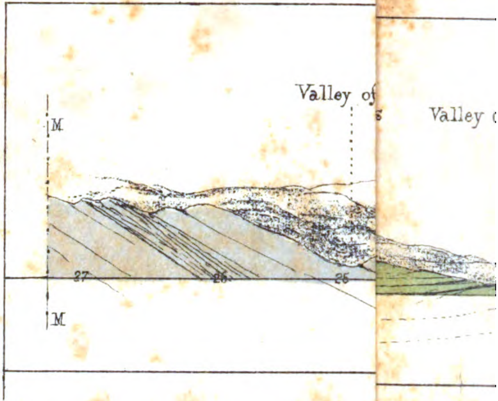
[2] Descripçion Geologica de Asturias, par D. Guillermo Schultz; Madrid, 1858, p. 14–15.

[3] Don G. Schultz, *Op. Cit.*, p. 21.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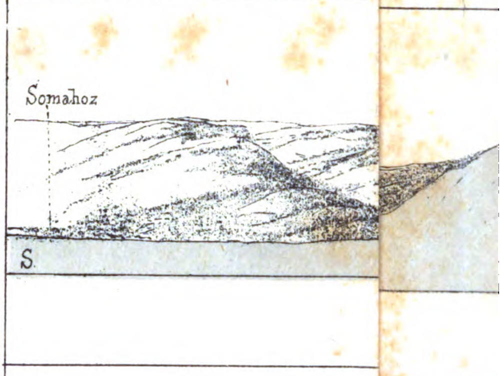
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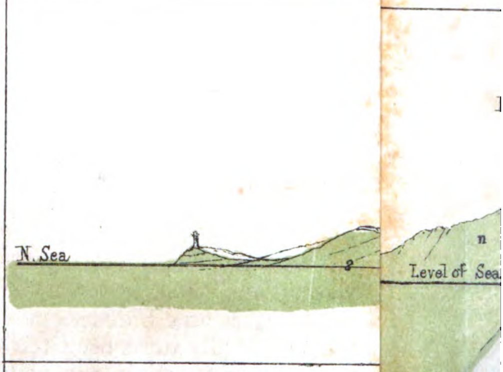
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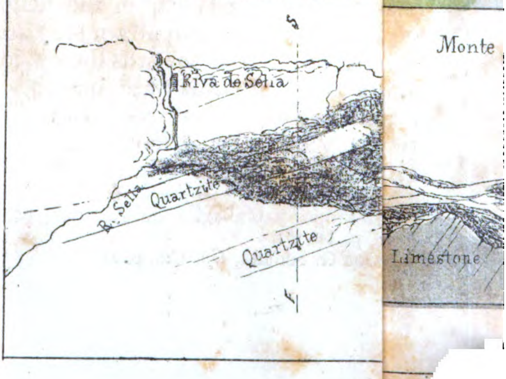
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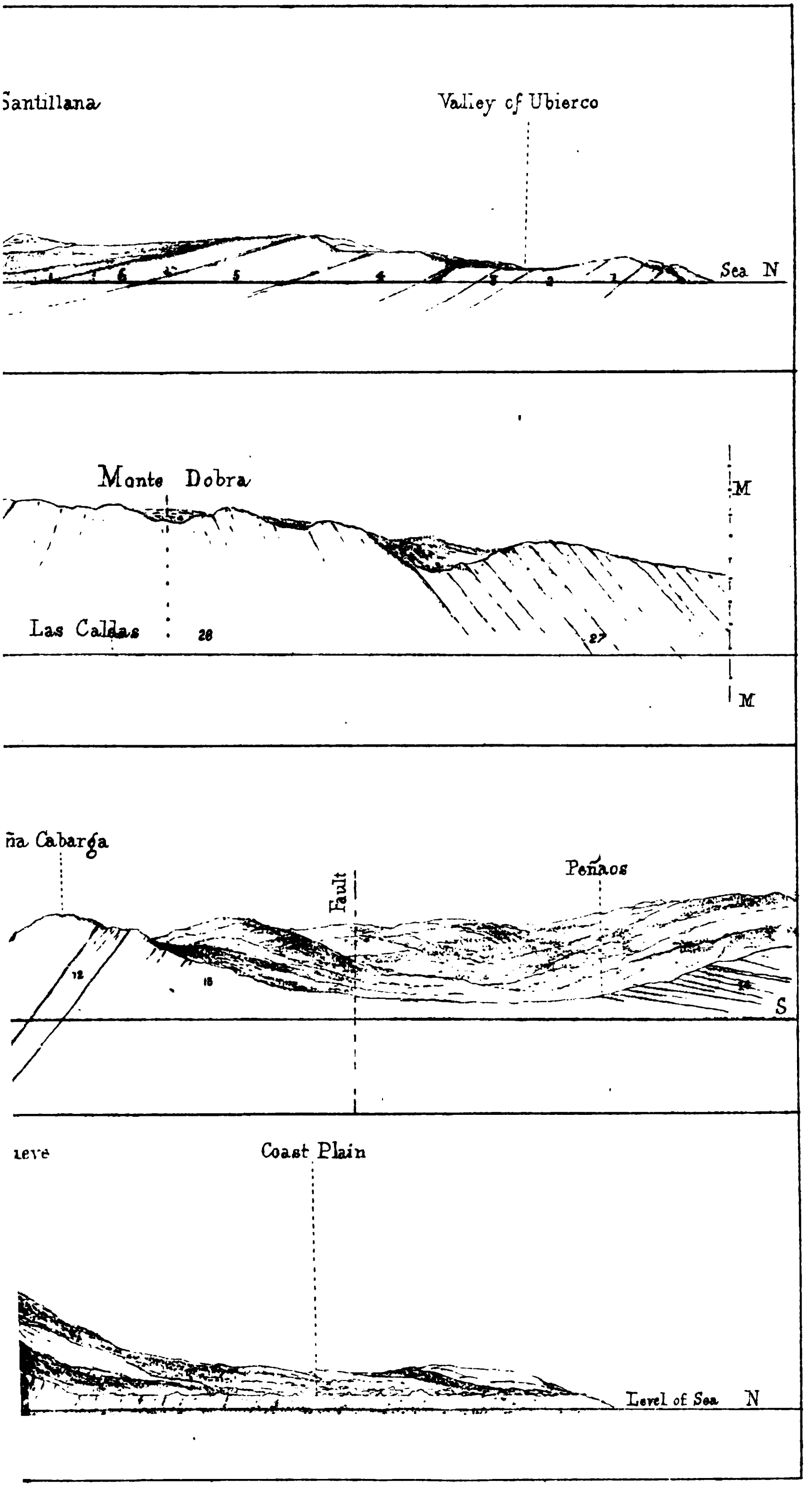
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the fine open valley of Merás, whose soft earthy soil would certainly have offered but little resistance to erosive actions. If further examples were necessary, we may mention the bend of the river Návia, called "del Pesebron", and that of the river Aranguin, which occurs in an extremely hard quartzite rock $2^{km.}$ west of Právia.

No more instructive examples of erosion, in the sense in which the word is usually understood as the result of the combined action of air and water in disintegrating and wearing down the surface of the earth, could perhaps be found than those *freitas*, *fanas*, and *escobios* of the Asturias, and we may add of Santander. In the latter they are, perhaps, less impressive by their magnitude, but are equally instructive. But although erosion is evidently the immediate cause of the river valleys, we have direct proof in both provinces of what we have above stated, that lines of fault or high folds directed the first erosive action. The bed of the Nalon, which Don G. Schultz describes as traversing the Devonian rocks along a fault or transversal plane of fracture with a distinct downthrow, traceable over the whole carboniferous formation for a distance of $60^{km.}$, is a very striking example of the combination of the two causes of the formation of river valleys.

It is impossible to properly understand the stratigraphical succession of the rocks of the province of Santander without taking into account the dislocations or faults which in many cases are perfectly visible, but, as may be expected, are still more frequently hidden by the surface vegetation and soil. The valley of the river Deva down to the sea, the estuary of Pesues, the valley of Potes on the N.W. side, the valley of the Pas, and more particularly in the neighbourhood of Ramales and La Nestosa, all reveal dislocations of very great magnitude, and seem to prove that the directions of the valleys were influenced by them.

§. 4. *Description of a section supposed to pass through the country between the sea and the Monte Dobra, passing through the Monte Vispieris, across the valleys of Reocin and Mercadal. Plate* 3, *Section* IV., *indicated by the line of section* HK *on the Map.*

On examining the cross section which passes near Santillana (Section HK on Map, and IV., Plate 3), it may be observed that the rocks composing the Monte Vispieris, situated about $800^{m.}$ to $1000^{m.}$ to the north of Puente San Miguel, present a nearly horizontal stratification. The old road from Santillana to the ferry, Barca Bareda, on the river Besaya, passes at its foot on the north side, and has consequently denuded a portion of the limestone, leaving a great number of fossils exposed, which are characteristic of the cretaceous formation. *Spondylus spinosus*, Defr., is here found forming compact beds of half a foot thick, intermingled with the spines of a Cidaris. The *Micraster coranguinum*, Ag., is nearly equally abundant. In this same bed *Terebratulæ* are abundant, whilst in others that under and overlie it, numerous specimens of *Turrilites* and corals (*Parasmilia centralis*, Edw., and a species apparently of *Litharaea*) are continuously to be met with.

Following up the succession of underlying beds as indicated in the cross section, we next meet with a sandstone, white when not coloured with iron, and sufficiently firm to be used as a building stone. This forms a range of low hills, overhanging the river Saya at Puente San Miguel, as seen in the section. Limestone crops out in the bed of the Saya from under this sandstone; the strata are tilted up, dipping north at an angle of about 15°. Although these beds are here covered by a deposit of white sand mixed with clay and alluvion, highly coloured by iron, they are nevertheless in immediate connection with the dolomite of Reocin, underneath which is found a bed of nearly dark gray limestone, characterized by the presence of large oysters and species of *Gryphæa.* This bed is similar to that which at Udias furnishes an excellent cement, and which will be described hereafter. To these succeed a series of beds of rocks, chiefly limestone, forming a ridge of low hills between Reocin and Mercadal, and some of which contain *Ammonites*, large *Pectens*, *Terebratula biplicata*, Sow., *Rhynchonella inconstans*, Sow., and in another is found a thick bed of *Orbitolina concava*, Lam. The latter fossil is also very abundant near Comillas, where, associated with *Rhynchonella depressa*, d'Orb., and *Terebratula Menardi*, Lam., it is in close connection with the dolomite.

A second bed of dolomite crops out in the neighbouring valley of Mercadal, and therefore appears to underlie that of Reocin; its development, although reduced, is nevertheless important.

Beneath the dolomite, which crops out on the north side of the valley of Mercadal, lie beds of sandstone and clay, and, lastly, a bed of limestone immediately overlying the red sandstone, and not separated from the latter on the section, which here attains considerable development relatively to the whole of the overlaying strata. The limestone of the Dobra range closes the whole series, and is represented, with its accompanying red sandstone, in the continuation of section IV., Pl. 3.

The Monte Vispieris, lying in the axis of a synclinal valley, the beds above described rise up between it and the sea, as is shown in the section. Following the line indicated therein, and which passes through Monte Vispieris, the limestone of this hill first crops out, then a green sandstone, next beds of limestone corresponding to those of the river Saya, and then the beds of dolomite, in which are found the mines of the valley of Ciguenza (Emilia mine). In the bottom of this valley, and covered over by a deposit of highly ochreous earth, is a supposed fault, the beds of limestone and the continuation of the dolomite on the other, or north side of the valley, presenting an anticlinal dip towards the sea at an angle of nearly 45°, so apparently in discordance with the dip on the south side as to have justified the foregoing hypothesis. Against the dolomite of the Fortuna mine lie beds of limestone, then the green sandstone already mentioned, and a succession of limestone beds corresponding to those of the Monte Vispieris.

To the north of the valley of Santillana the succession of beds observed between Monte Vispieris and Puente San Miguel is repeated in an opposite direction: the dolomite also comes up in the valley of Ubierca, where traces of calamine and blende have been recognized in the joints of the dolomite under conditions perfectly similar to those presented by the valleys of Reocin, Ciguenza, Novales, etc.; between the dolomite and the sea the underlying limestone also crops out.

The second bed of dolomite, or that of Mercadal, is to be considered as part of the same bed which appears at Reocin. Its very limited extent, its peculiarly fractured condition, and the rocks associated with it, necessarily lead to this conclusion. Moreover, the comparison of the beds of Mercadal with those of Udias, where the succession of beds is so well seen, leads to the conclusion that the dolomite of Mercadal is identical with that of Udias also. Now at the Rasa we have apparently several beds of dolomite, but the numerous faults which are distinctly recognizable in the valley clearly explain this repetition of the same bed. If, therefore, it be demonstrated that at Udias the beds of dolomite apparently distinct are nevertheless but dislocated portions of one and the same bed, we may reasonably assume that the beds of Reocin and Mercadal are similarly related. The dips of the rocks are nearly identical, and no trace of a fold can be recognized, so that the position of the beds is to be explained by an east and west fault, with an upthrow of the beds to the north of a line between Reocin and Mercadal. There is even reason to believe that this fault is but the continuation of one of those which are so well exposed in the valley of Udias and the Rasa hills, and of which we have already spoken.

We may now give the succession of beds, such as they present themselves along a section from the sea by Ubierca, Monte Vispieris, Puente San Miguel, valley of Reocin, valley of

Mercadal, Monte Dobra or Las Caldas, and ending in the valley of Los Corrales.

1. Thick beds of gray limestone (containing *Ammonites*, large *Pectens*, etc.).
2. Dark gray marly limestone of the same nature as that which produces hydraulic lime. Thin beds of sandstone and clay.
3. Dolomite of Ubierca.
4. Soft argillaceous sandstone.
5. Very light gray limestone.
6. Greenish or brownish soft sandstone with thin intercalated beds of clay.
7. Limestone, rather lighter coloured than No. 9, but sometimes tinged brown by peroxide of iron, and containing *Ostrea carinata.*
8. Thin beds of marly clay and limestone of a dark blackish colour, and of inconsiderable thickness.
9. Beds of green and somewhat earthy limestone, apparently capped by greenish calcareous sandstone, containing *Spondylus spinosus*, Defr., *Diadema granulosum*, Ag., *Micraster coranguinum*, Ag., *Terebratulæ*, *Turrilites*, etc. This limestone forms the mass of the Monte Vispieris, and is the uppermost in the whole section.

   The beds here form a synclinal, and are consequently repeated in a reverse order to the south.
10. Thin beds of marly clay and limestone of a dark blackish colour and of inconsiderable thickness (being the continuation of No. 8).
11. Limestone of rather lighter colour than No. 9, but sometimes tinged brown by peroxyde of iron, and containing *Ostrea carinata* (continuation of No 7).
12. Greenish or brownish soft sandstone with thin intercalated beds of clay (continuation of No. 6).
13. Very light gray limestone, containing *Parasmilia centralis*, Edw., and what appeared to be a species of *Litharæa* (continuation of No. 5).
14. Soft sandstone, in the upper part presenting more the appearance of an alluvial deposit on account of the abundance of oxides of iron and manganese, as also of blue clays and white quartz shingle or coarse gravel. This character was observed in the shaft opened over the dolomite of Reocin, on the top of the hill which divides the two valleys of Reocin and Puente San Miguel. The quartz gravel was perfectly white and of various sizes, many pebbles being the size of an apple. The clay was in some parts quite white (a character which also occurs in the beds of sandstone to the south of the dolomite at Comillas), and was found more abundantly in another cutting opened near the foot of the hill on the south side of the valley of Puente San Miguel. (This bed is the continuation of No. 4.)
15. Dolomite of Reocin (continuation of that of Ubierca).
16. Beds of a dark gray marly limestone of the same nature as that

which produces the hydraulic lime at Udias. It contains *Ostrea deltoidea*, Sow. (0^m15 long, and 0^m10 wide).

17. Beds of sandstone and clay, not very thick. (The beds No. 16 and 17 correspond to No. 2.)
18. Thick beds of gray limestone, containing *Ammonites* 0·20 in diameter, large *pectens*, or more probably *Pholadomya lyrata*, Sow., and a bed of the coral *Calamophyllia Stokesii*, Edw. (?) (corresponds to No. 1, which forms the coast at Ubierca).
   Here the fault is supposed to have occurred which was accompanied by the upthrow of all the preceding beds relatively to those which here follow, and of which some are of course repeated between this point and the dolomite of Mercadal.
19. Dark marly clay and limestone.
20. Thick beds of gray limestone, *Rhynchonella inconstans*, *Orbitolina concava*, *Terebratula biplicata*, or more probably *T. sella*, are found in this and the preceding beds.
21. Dark gray, brown, and red slate clays. The beds 19, 20, and 21 correspond to the beds 10, 11, 12, 13, and 14.
22. Dolomite of Mercadal.
23. Beds of hard slaty clay, with plates of an ash-brown marly limestone, corresponding to 16 and 17.
24. Hard limestone, the upper beds marly and of a dark gray colour and very similar in texture to the beds which at Udias and Novales underlie the dolomite. In them have been found at Mercadal *Pecten cingulatus*, Goldf., *Cardinea lanceolata*, Stutch., *Isocardia*, and what appears to be the *Inoceramus Hamiltoni* of Portlock, etc.
25. Beds of clay presenting various shades of ochre, red, brown, gray, alternating with beds of sandstone, slightly red, near the junction with No. 24, but becoming thoroughly red, hard, thick, and micaceous in the inferior beds.
26. Thin beds of dark gray marly limestone, alternating with thin beds of very dark gray marly clay, and forming a band between the upper and lower sandstone beds, Nos. 25 and 27.
27. Thick massive beds of red sandstone, hard and micaceous, alternating with thin beds of clay.
28. Dobra limestone.
29. Repetition of bed No. 25.

§. 5. *Description of a section supposed to pass through the Bay of Santander, the Peña Cabarga, into the Valley of Peñaos. Plate* 3, *section* V.; *indicated by the line of section* LM, *on the map.*

The district in the immediate neighbourhood of the town of Santander is greatly disturbed by faults, so that it is very difficult to determine the true relations of the different rocks which occur in it. In attempting to represent by a section our interpretation of the phenomena observed there, our object is simply to supply a basis for future and more detailed observations, as a simpler explanation may, probably, be given than that suggested by us, when the locality shall be further studied.

To the north of the town of Santander, and between it and the lighthouse, the cretaceous rocks developed in the province may be well studied. The beds dip regularly to the N., and apparently without being contorted. The town itself is built upon a compact gray limestone, indicated in the section by No. 5, which is employed for building stone, and which contains large *Exogyras*, the species of which cannot be easily determined. Immediately to the north of the town are found clay marls, and a quartzose grit forming a hillock, and indicated by No. 4. Still further to the north come a range of low hills composed of argillaceous limestone, No. 3, containing several species of *Orbitolites*, one of which, five centimetres in diameter, appears to be referable to the *Orbitolites plana*, d'Arch. Species of *Terebratulae*, *Hemicidaris*, and apparently *Discoidea subuculus*, Ag., are also found in it. To these succeed the argillaceous marls No. 2, full of disseminated green points, and containing *Ammonites Mantelli*, Sow., *Hemiaster bufo*, Ag., etc. A depression or valley, which traverses the promontory from W. to E., occurs here, and is occupied by a marsh and some sand dunes, to the north of which the ground rises again into a headland with picturesque escarpments, at the extremity of which is situated the lighthouse The cape or headland is formed of argillaceous limestone and a hard grit, No. 1, the former constituting the precipices just mentioned. The limestone is full of sponges, and contains, besides other species, *Micraster coranguinum*. Some beds of underlying grit are mixed up with clay, and are sometimes almost entirely made up of fragments of species of *Inoceramus*, *Pecten*, and *Ostrea*. This series of beds has been described by M. de Verneuil; and in the summary which M. d'Archiac gives of the observations of the latter, he refers them to the chalk marl. They appear to us, however, to coincide fully with the succession of beds observed elsewhere above the dolomite.

The limestone, No. 5, which forms the base of the preceding series, borders the Bay of Santander to the north; the beds are almost vertical, but their inclination is to the north. The dolomite, No. 6, crosses the Bay near Peña Castillo and to the south of this rock, and comes out again on the south-eastern shore, its dip being still to the north, but now, however, at an angle of only about 12° to 15°. Traces of blende and calamine occur in it here, near the level of the sea. In the Bay of Santander, at about $800^{m.}$ to $1000^{m.}$ from Peña Castillo, immense deposits of gypsum are found in a highly plastic purplish or reddish clay. Similar deposits also occur on the south side of the bay, near the foot of the Monte Cabarga, where the high road is cut through them. It is very difficult to determine to what formation this gypsum belongs; it may belong to the lower part of the lias, or may be only a local newer deposit.

To the south of the first of these deposits the peninsula of Maliano projects into the bay. We have assumed that this promontory forms a synclinal which is bounded by two faults, one to the north and the other to the south. The promontory itself consists of almost horizontal beds of a light gray limestone, No. 8, containing a species of *Rhynchonella* and large *Ammonites*, and having large joints filled with brown hæmatite. Immense deposits of similar ore are found in the bay. We have supposed its northern bounding fault to have occurred in the limestone underlying the dolomite; the latter comes out near the eastern extremity with a dip of 40° to 45° north, and contains traces of blende; we have therefore assumed it to exist in the bottom of the bay to the south of the peninsula. On the opposite side of the *Ria*, or channel, at Astillero, thin beds of dark gray marly limestone crop out, with a high dip to the north, and alternate with beds of dark gray marly clays, being apparently a continuation of the similar beds which occur between Guarnizo and Boo, where, however, their dip is low, though still to the north. Both the limestone and the clay crumble away continuously where exposed to the action of the atmosphere.

The beds, No. 10, just described, are in contact with a yellowish sandstone abounding in indications of iron ore, which covers the surface of the Monte Cabarga on both sides. To this sandstone succeeds the limestone No. 11, which overlies the dolomite, and which forms the escarpments of the Monte Cabarga, dipping here at an angle of 45° to 50°. The beds marked 11 appear to be cretaceous, and consequently we have assumed the southern fault to have occurred along the line of junction of 10 and 11, at Astillero, near the high road which runs along the foot of the Monte Cabarga, as indicated upon the section. On the south side of the Monte Cabarga the dolomite, No. 12, crops out, underlying the limestone No. 11, and is here perfectly well marked, but no indications of ores have as yet been found in it. Beneath these crop out the same beds of black marly clay, in which have been found *Ammonites bifrons*, Brug. The greater part of the surface of the northern part of the valley lying between the Monte Cabarga and the village of Peñaos is thickly covered by granular brown hæmatite. At the village of Peñaos itself and to the south of it, beds of black marly clays and sandstones, dipping at an angle of 10° to 15° to the south, and containing *Belemnites* and *Rhyncho-*

nella rimosa, Buch, and in the sandstone thin beds of lignite occur. The bottom of the valley presents an apparent anticlinal, but the lithological character of the beds and the variation of the dips can only be satisfactorily explained by a fault with an upthrow to the north, similar to what has occurred at Udias and Ciguenza.

§. 6. *Conclusions deducible from the comparison of the foregoing Sections.*

Before attempting to summarize the conclusions which we think are deducible from the observations contained in the preceding pages, a few words upon the origin of the paper itself are necessary in order to show its proper character. In commencing it our object was simply to place on record a series of observations upon the position, mineralogical character, and chemical composition of the zinc ores of the province of Santander, before the most typical of them shall have disappeared for ever. In doing this, we must of necessity have referred to the geology of the district, but it formed no part of our plan to discuss that subject at any length. As we proceeded, however, we found, step by step, that the different subjects were too intimately ramified with each other to be dissociated; and, as no satisfactory results could be obtained until we had first determined the leading features, at least, of the geology of the district, we determined to preface our mining and mineralogical notes by a short sketch of the geology of those parts of the province in which were situated the mines.

To do this our means were imperfect. In the first place, we were very unfavourably situated for obtaining information as to what had been done previously upon the subject, and it was too late to attempt to get a long series of Spanish journals, in the hope of finding short papers upon the geology of the north of Spain. For, with the exception of the work of Don G. Schultz upon the province of the Asturias, we are not aware that any Spanish geologist has yet published a detailed memoir upon the country north of the Cantabrian chain. Nearly the whole paper was written and set up in type, and we had formed our opinions upon the formations which we believe to be represented by the rocks of the province, before we became aware that M. E. de Verneuil had written upon its geology, and had even published a section across Spain, from Santander to Motril, which therefore intersects the whole province. This paper we have not, unfortunately, seen, for no public library in Dublin available to us has a complete set of the *Bulletin de la Société Geólogique de France*, in which the memoir was published.

What we have said above about the way in which our purely mineralogical memoir grew into a geological one, will explain why we did not procure M. de Verneuil's paper directly. We are, therefore, only acquainted with that geologist's views through the abstract given in the fifth and seventh volumes of M. A. d'Archiac's admirable *Histoire des Progrès de la Geologie*, M. Dumont's geological map of Europe, and the very brief notice given of his papers in Leonhardt's and Bronn's *Jahrbuch*.

Our second difficulty was the want of an extensive collection of fossils. The notes of Mr. O'Reilly mentioned the occurrence of a great many fossils at different points through the province. But we thought it better in most cases not to make any use of those, or any other notes, except where we had the fossil itself before us. Although the number of fossils which we have mentioned in the preceding pages, or may mention hereafter, be small, they are nevertheless characteristic.

Our third difficulty was the want of a good topographical map, to serve as a basis of our outline map of the province. We had not time to endeavour to procure a Spanish one, and were obliged to be contented with an old French one, the orography of which was very defective. With this, aided by the topographical map of the province of the Asturias by Don G. Schultz, the outline map accompanying this paper was prepared. For our purposes it is accurate enough.

On the whole, we are not sorry for the accident which prevented us from becoming acquainted fully, or earlier, with M. de Verneuil's views; as the general concordance of our conclusions, especially upon one of the most important points of the geology of the country north of the Cantabrian Pyrenees, is the more valuable from having been the result of wholly independent observations. It is also satisfactory to us to find that those views are likewise in accordance with most of those held by M. Louis Javot, engineer to the Company of the Mines and Foundries of Santander, to whom we are indebted for much valuable information, and whose genuine scientific taste is no where better shown than in the ready liberality with which he places the results of his long experience at the service of his friends.

In attempting to summarize such details as the foregoing pages contain, and to deduce from the comparative study of the sections, the stratigraphical succession and relative ages of the different rocks found in the province, the first thing to be done is obviously to establish certain definite horizons. The nummulitic series offers us one, which is not only convenient as being the newest, or uppermost, but is also topographically the first, the rocks being near the sea shore. The boundary of the nummulitic rocks may be drawn along the N.W. of the province, from the confines of Asturias, by Columbres, Pesues, the south side of San Vicente, near Roiz, and then towards the N.E., so as to cut the coast between the eastern extremity of Cabo Hoyambre and the mouth of the Rabia. The whole of the nummulitic beds in the province lie north of this line; their dip is variable, but generally between 20° and 40° N. At Pesues and at Columbres these beds are in immediate connection towards the N. with elevated sandstone table mountains, the true character of which has not yet been determined. According to Don G. Schultz, they are carboniferous, as we have coloured them; but on the geological map of M. Dumont they are comprised in the nummulitic group.

The nummulitic rocks rest on cretaceous rocks which occupy a portion of a narrow band of country near the sea, in the west of the province, which becomes largely developed towards the E. The rocks which are found on the north side of the bay of Santander are cretaceous, and have been studied by M. de Verneuil, who considered the beds lying between the bay and the lighthouse to belong to the upper chalk marls, and in the description of the sections we have sufficiently established their position as respects the nummulitic beds, as our first horizon. Now those beds which form the foundation of the quay of Santander strike off towards the W., and are found to overlie not only the dolomite of Peña Castillo, and the immense mass of the same rock lying about the S.W. part of the Bay of Santander, but may also be traced along the coast at Puente Arce, Torre la Vega, Puente San Miguel, Oreña, Novales, Comillas, La Rabia, San Vicente, and up to San Pedro, on the banks of the Deva, and still further inland at Reocin, Mercadal, Udias, Cabiedez, and La Florida. At all those points the succession of rocks may be considered as identical, and their connection with the dolomite the same as at Santander.

This dolomite, of which we consider there is but one important bed in the whole province, is considerably developed, being in some places 120$^{m\cdot}$ thick; it is also so lithologically unlike any cretaceous rock with which we are acquainted, that, if for no other reason, we would have doubted that it belonged to the cretaceous formation. That it does not, is proved by the fossils found in the underlying rocks, such as *Calamophyllia Stokesii*, *Rhynchonella rimosa*, Buch, *Ostrea deltoidea*, Sow., *Pholadomya lyrata*, Sow., *Ammonites bifrons*, Brug., *Ammonites serpentinus*, Schloth., large *Pectens*, and abundant *Belemnites*, all of which are undoubtedly jurassic. The dolomite itself also contains fossils, more or less distinct, according to the peculiar local texture of the rock, and in it have been found by M. Louis Javot, *Ammonites* of a large size, similar to those in the underlying beds. We may therefore look upon this dolomite as the top of the jurassic formation, and consequently as our second well defined horizon.

The cretaceous and jurassic formations exhibit generally an apparent conformability, so striking that there can be no doubt that many geologists did not recognize the dolomite on this account. M. d'Archiac, in summarizing the results of M. de Verneuil, no where mentions it, at least we did not recognize any reference to it. At their junction, the rocks of both formations have a comparatively high dip, but to the north it diminishes so much, that the cretaceous beds appear to be almost horizontal, and to rest in shallow synclinal troughs of the jurassic rocks.

The cretaceous rocks appear to underly everywhere the nummulitic formation, and consequently to stretch in a comparatively narrow band from Columbres eastward towards the province of Biscaya, widening out towards the east beyond Santander, until it forms a considerable breadth of the northern flank of the main chain. A number of N.W. and S.E. faults, with corresponding N.E. and S.W. dislocations, accompanied by upthrows and downthrows, subsequent denudation and erosion of river valleys, have laid bare at many points along this narrow band of cretaceous rocks the underlying jurassic rocks. Where this occurs, the tops of the hills and the higher parts of their declivities are cretaceous, while the troughs of the valleys are in jurassic rocks.

The succession of beds for the different sections given in the foregoing table could, no doubt, be made more detailed and precise in some points, but even as the tables stand, their coördination enables us, we think, to distinguish three more or less well marked horizons. The first consisting of white or greenish soft sandstone, immediately underlying the nummulitic limestone, and which are frequently more like conglomerates than sandstones, shaly marly clays, and argillaceous and arenaceous limestone, containing abundance of *Micraster coranguinum*, Ag., *Spondylus spinosus*, Defr., *Hippurites organisans*, Desm., *Sphærulites Toucasi*, Bayle, *Ananchites subglobosus*, Lam., *Diadema granulosum*, Ag., *Parasmilia centralis*, Edw., *Terebratulæ*, *Turrilites*, etc. These beds, which correspond to No. 5 and 6 in the section of San Vicente, 1 to 6 of Comillas, and 8, 9, and 10 of the Monte Vispieris section, are far more developed than any of the others, the whole thickness of which is represented by the height of the Monte Vispieris, which is wholly made up of those beds, and which may therefore be estimated to have a thickness of about 100^{m}. We may consider them as the representatives of the chalk marl, or *Terrain Turonien* of M. Alcide d'Orbigny.

The second cretaceous horizon would consist of thick beds of gray limestone, sometimes hard and shelly, thin beds of marly clay and ochry sandstone, represented by 7 and 8 in the San Vicente section, 6 to 9 in that of Comillas, and 7 to 11 in that of the Monte Vispieris, and characterized by the fossils *Hemiaster bufo*, Des., *Sphærulites polyconilites*, Bayle, *Ammonites Mantelli*, Sow., *Ostrea carinata*, Lam., *Neithea quinquecostatus*, Br., *Exogyra haliotoidea*, Goldf., *Caprina adversa*, d'Orb., *Turrilites costatus*, Lam , and many casts of other species of *Ostrea*, *Pecten*, and of *Nerinea*, etc. These fossils belong to the upper green sand, or *Terrain Cenomanien* of M. d'Orbigny, and the rocks containing them may perhaps represent that group.

The third horizon would consist of thick beds of dark or light gray limestone, greenish or brownish soft sandstones, sometimes argillaceous marly clay, and thin beds of limestone, and dark slate clays, represented by No. 9 of the San Vicente section, No. 10 of the Comillas section, Nos. 4 to 6, 12 to 14, and 19 to 21 of the Monte Vispieris section, and characterized by the fossils *Terebratula sella*, Sow., *Orbitolites concava*, Lam., *T. Menardi*, Lam., *Rhynchonella depressa*, d'Orb., *Trigonia caudata*, Ag., *Trigonia dædalia*, Park., *Cyprina angulata*, Flem. (?), *Caprotina Ammonia*, d'Orb., another species of *Cyprina*, etc., all of which belong to the lower green sand, or upper *Neocomien* of M. d'Orbigny.

This third cretaceous zone is everywhere in contact with the dolomite, and completes the proof that the dolomite is jurassic. These three zones are recognized by M. d'Archiac in his analysis of M. de Verneuil's paper, in the following passage: "One sees thus, that on the northern flank of the Cantabrian chain the cretaceous formation appears to be composed of three series of beds, or *étages*, sufficiently well characterized by their rocks and their fossils. The lower comprises a sandstone and a compact limestone with *Requienia*, large oysters, *Orbitolites conica*, etc. The second, marly and argillaceous limestones and different sandstones, with *Orbitolites plana*, *Hemiaster bufo*, *Ostrea carinata*, *Radiolites polyconilites* and *crateriformis*, and *Ammonites Mantelli*. Finally, the third, sandstone and argillaceous limestones, rather thick, with *Micraster coranguinum*, or *M. brevis*, and numerous species of *Inoceramus*".[4] He then goes on to say: "The observations of M. de Verneuil lead us to this first conclusion, that, as *à priori* we might have suspected, in consequence of their geographical position, the Gault and the Neocomien group is wanting on the northern flanks of the Pyrenees, exactly as we have seen more to the east in the Basses Pyrenees and the Landes, to the N.E. on the opposite shore of the cretaceous sea in Périgord, Angouleme, and Saintonge, and finally in the basin of the Loire". It is clear enough from the foregoing passage, that M. d'Archiac, and, as we may infer, M. de Verneuil, do not recognize the existence of the lower green sand in the province of Santander, and accordingly the former has been endeavouring to coördinate the rocks of that province with the cretaceous band of the south-west and of the central plateau of France, which he has himself so well studied. Although several of the fossils which characterise our third horizon are found in the typical Cenomanian beds of Mans itself, we think it probable that our lowest beds represent the lower green sand or upper Neocomien. This view is supported by the occurrence in the corresponding beds of the Asturias of *Toxaster complanatus*, Ag., *Exogyra Bousingaulti*, d'Orb., *Ostrea macroptera*, Sow., etc. The coördination of the beds of different areas, and the determination of their relative ages, are, however, questions which can only be determined by a thorough investigation of a large series of fossils.[a]

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[4] Histoire des Progrès de la Géologie, de 1834 à 1852, par A. d'Archiac, t. v. p. 46.

A glance at the table of the succession of rocks shown by the section from Ubierca to Los Corrales, will show that, with the exception of a narrow strip of the lower green sand, preserved as it were by the upthrow of the beds north of a line between the valleys of Reocin and Mercadal, a considerable belt of land is occupied by beds, some of which are undoubtedly jurassic, and the top of which is formed by the dolomite. About the upper boundary, therefore, no difficulty exists, but it is otherwise with the lower limits. Beneath the dolomite we find a series of beds of hard shelly argillaceous limestone, with thin slaty clay and marly limestone beds, variegated clay beds passing into reddish-gray sandstone in their lower part, thin beds of dark gray marly limestone alternating with thin beds of very dark gray marly clay, beneath which are found thick beds of red micaceous sandstone, with thin partings of clay. We next come to great beds of a compact blue, and often almost black limestone, very much jointed, and containing metalliferous deposits, and forming the axis of the east and west chain called the Dobra. Beyond the Monte Dobra, in the valley of Los Corrales, we have a repetition of the thick beds of red sandstone found on the north side of the range.

In the upper members of this series, many jurassic fossils have been found, but in the great beds of red sandstone, no fossils have to our knowledge been met with. Hence, the question arises, are all these beds jurassic, or does the red sandstone represent an island of the trias? It is very difficult to admit the latter hypothesis. In the first place, the character of the dips would only admit of the existence of such an island, by supposing a fault with an upthrow to the N., similar to that we have assumed between Reocin and Mercadal. This upthrow should be considerable, and should occur about No. 26 of the beds of the section from Ubierca to Los Corrales. But this would create a still greater difficulty, for there is no rock corresponding to the Dobra limestone to the north of that chain.

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[a] We take this opportunity of thanking Mr. W. H. Bailey, Palæontologist to the Geol. Survey of Ireland, for much kind assistance in determining fossils.

There are, in fact, but two hypotheses which are sufficient to meet the physical conditions of the problem. We shall leave for the moment the palæontological part of the question aside. The first is, to assume that the rocks between the dolomite and the Dobra limestone include both jurassic and triassic rocks, and that the Dobra limestone itself is carboniferous. The second would be, to assume that all the rocks between the dolomite and the Dobra are jurassic, including the Dobra limestone itself.

The former hypothesis appears at first sight the simplest, and was the one originally adopted by M. de Verneuil. M. d'Archiac tells us,[6] "at the village of Puente Viesgo, the new red sandstone is found with saline springs; it is the prolongation of that of Llerganes, near the Cabada, contains gypsum, sulphureous waters, and presents all the characters of the trias. Slightly developed in this place, it is soon replaced by very thick metalliferous limestone, greatly dislocated, which M. de Verneuil considers as forming a continuation of the carboniferous limestone of the mountains of Cavadonga, of Puerto Sueve, and which advances as far as the shore of Riva de Sella". The lithological character of the Dobra limestone is, however, very unlike that of the usual carboniferous limestone; it is blackish and streaked. The beds appear to be perfectly conformable with the overlying sandstone. This conformability is well seen immediately to the south of Udias, beyond the plain of Cabazon de la Sal; the Dobra chain is here cut by a transverse pass or valley, in which flows a stream. The erosive action of the water has uncovered a portion of the underlying blackish limestone which is perfectly concordant with the overlying sandstone. Another striking example of this concordance is to be seen on the east side of the valley of the Deva, about 3,000$^{m.}$ to the south of the hot springs of the Hermida, not far from the mines of Linares.

The difference in lithological character, and the conformability with the red sandstone, but, above all, the necessity, as appeared to us, which would arise of assuming the existence of a very complicated system of faults accompanied by enormous dislocations, not in harmony with the orographical features of the country, to account for the relative positions of the carboniferous rocks in this and the neighbouring province, led us to suspect that the second hypothesis was the correct one, and that the Dobra limestone was jurassic. This appears to be now the opinion of M. de Verneuil also, as the following observations of M. d'Archiac shows: "In a section directed N. and S. from Santander to the Cantabrian chain, M. E. de Verneuil, after a first voyage, made in the spring of 1849, showed that from beneath the cretaceous beds dipping to the N., sandstones, conglomerates, and blue argillaceous limestones, belonging to the lias, successively elevate themselves, and having the same dip. These limestones, characterized by *Belemnites* and *Ammonites Conybeari*, repose on the trias, represented by red sandstone with salt and gypsum. This system appeared at the time to unconformably recline against vertical beds, contorted and dislocated, more ancient, and belonging to the carboniferous limestone; but later observations enabled him to recognize that the whole was connected with a jurassic band, running from E. to W., from La Cabada to Fuente de Nansa, having a length of twelve leagues, and a breadth of three, under the meridian of Santander. It surrounds to the south of Vargas an island of trias in the form of a crescent, and is circumscribed by cretaceous beds. To the west it rests against the trias from Fuente Nansa to Reynosa, and beyond it. At Rosas, M. Ezquerra del Bayo mentions *Pecten æquivalvis* and *Melania Heddingtonensis*".[7]

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[6] Op. cit., p. 45.

It would appear from the passage just quoted, that this jurassic band ended in the valley of the Nansa, where it rests against the triassic rocks. We are to suppose that this in turn rests towards the west upon the carboniferous formation. According to the map of Don G. Schultz, the valley of the Deva is chiefly occupied by carboniferous rocks, with the exception of the patch of cretaceous rocks capped by the nummulitic beds of Columbres, and another south of Alevia, mentioned at page 14. In the map of M. Dumont also, the nummulitic beds of San Vicente, and the underlying cretaceous rocks, are made to extend to Columbres, and to form the sea coast. At the former place the cretaceous rocks rest on jurassic ones, while at Columbres, according to Don G. Schultz's map, the same rocks rest on carboniferous beds. The same phenomenon appears to occur in the province of Palencia, to the south of the main chain, where, according to Don Casiano de Prado,[8] the cretaceous beds rest indifferently upon jurassic, triassic, carboniferous, and even Devonian rocks in the province of Leon. This circumstance would not consequently afford a ground for not believing that the jurassic rocks end in the valley of the Nansa. But now that we find jurassic rocks farther north than Puente de Nansa, that the sandstones which appear to bound the jurassic rocks to the west, overlying the Dobra limestones, as is plainly seen near Linares, almost in the valley of the Deva itself, and, lastly, that dolomite occurs at San Pedro, between the Nansa and the Deva, we are obliged to admit that the jurassic band extends to the Deva.

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[7] Op. cit., t. vii. p. 172.

[8] Op. cit., t. viii. p. 172.

But as all the rocks in the valley of the Deva, from Alevia to Potes, appear to belong to the same formation, and as the principal limestone is lithologically the same as that of the Dobra chain, we are compelled to make the whole of the rocks, from the chalk and nummulitic beds of Columbres to Potes, jurassic. So that, in this case, the mountain to the north of Alevia, forming the western end of the Sierra de Cuera, should be placed in the jurassic formation. But this is not all: if the Dobra limestone be jurassic, the eastern part, if not the whole of the Picos de Europa, the highest peaks in the whole Cantabrian chain, which reach 2600 ·, are likewise jurassic.

Don G. Schultz makes the Picos de Europa, and the whole district to Alevia, carboniferous; the hypothesis just stated is consequently in direct variance with the conclusions of that geologist. But if M. de Verneuil's opinion with regard to the limestone of the Dobra at Puente Viesgo be correct, and with that opinion we agree, having, as we have before stated, come independently to the result that it must be jurassic, then the conclusion appears to us to be inevitable, that the jurassic formation extends into the province of the Asturias, and that the whole of the geology of the eastern part of the province just named requires rectification.

Two important circumstances appear to support the jurassic character of the whole of the limestone of the Deva, namely, first, the similarity of lithological character between the limestone of Merodio and that of Tresviso, and higher up in the chain, a character which is quite jurassic; secondly, the unconformability between this limestone and the slate clays, quartzose sandstone, and quartz conglomerate, which underly it in the valley of Potes, and which, in their continuation to the west, are looked upon as triassic. This unconformability is well seen in the section along the valley of the Deva, and is rendered more evident by the occurrence of a grit at the base of the limestone in the valley of the Deva. In the section through the valley of Potes, it will be seen that the slate clay rests upon a quartzose sandstone, and towards the west, thick beds of quartz conglomerate are associated with the latter (see description of the mine of Piço Jano, page 81).

The supposed triassic beds of Potes form to the E. and S.E. some mountains of considerable altitude, to the south of which a limestone, similar in character to that of the Dobra, rests upon them. The relationship of the two will be found indicated in the description of the mine "del Soto", page 80. These jurassic rocks appear to run westward along the southern flanks of the main chain, whence the Ebro derives its waters, and on towards the province of Leon; so that we may expect to find jurassic limestone resting upon quartzose sandstone, to the south of Pico Jano, exactly as at "El Soto". To the N. and N.E. of Reynosa, in the Sierra de Sejos, the same rocks as are found in the valley of Potes appear to occur, and to the south of them, as at the Porto Escudo, jurassic limestone. It would thus appear that a band of rocks, believed to be triassic, composed of slate clays, quartzose sandstone, and quartz conglomerates, and in places gypsum and salt, and underlying the limestone of the great Picos de Europa, runs from the valley of the upper Deva, eastward to the Sierra de Sejos, forming the ranges of the main chain south of the Picos de Europa, which are probably due, at least in part, to an independent series of upheavals.

The geological map of France of MM. E. de Beaumont and Dufrenoy includes the part of Spain immediately lying on the flanks of the Pyrenees: the chief geological features of the province of Biscaya, which bounds that of Santander on the west, are therefore to be found upon it. According to it, a patch of jurassic rocks occurs in the former province, and another patch is shown upon the map of the Asturias of Don G. Schultz, between Villa Viciosa and Colunga on the sea coast. It would thus appear that a great band of jurassic rocks extended from S.E. to N.W. along the northern flank of the Cantabrian chain. According to the map of the Asturias, the Colunga rocks are not connected now with those of the province of Santander, a large area of carboniferous rocks intervening. The Biscayan rocks are likewise represented on the French map as an island surrounded by cretaceous rocks. It is probable that the cretaceous rocks are thicker and less denuded to the eastward, and that perhaps in some places the jurassic rocks are wholly concealed by the cretaceous ones. We have reason to believe, however, that the dolomite of Santander is continuous into western Biscaya, and that perhaps all the ores of that province, especially its celebrated carbonate of iron, like the ores of Santander, are connected with that rock. If, however, we conclude that the jurassic formation extends to the Deva and beyond it, and that consequently a part of Don G. Schultz's carboniferous rocks are in reality jurassic, the Colunga rocks may be continuous with those of the province of Santander.

At San Vicente de la Barquera the cretaceous rocks rest upon jurassic ones, and upon the former rest tertiary rocks represented by the nummulitic beds. At Columbres the nummulitic rocks rest upon cretaceous beds to the south, while to the N., or rather N.W., it thus seems to be in direct contact with the quartzite of Tina Mayor. This quartzite appears to be in contact with the northern boundary of the nummulitic from near Pesues, where the nummulitic enters the sea, westward to Columbres; it alternates with a hard gray limestone along the coast by San Antolin to Riva de Sella, and both are lithologically unlike any rocks in the province of Santander, and appear to be true members of the carboniferous formation, in which they have been placed by Don G. Schultz. These rocks dip N.W. at a high angle, being in some places almost vertical, so that the beds come out obliquely on the sea coast, where they present a very singular phenomenon. At the distance of about two kilomètres from the coast these rocks near Riva de Sella form lofty and wild mountains, while along the coast they form a series of narrow and almost perfectly level platforms, elevated from forty to one hundred metres above the sea. In Plate 3 will be found a map of the coast between Riva de Sella and Tina Menor, and also a section, FS, taken between San Antolin and Riva de Sella, which show the relation of these remarkable platforms to the mountains to the south. It will be seen that the highly inclined strata have been cut, just as would happen on a small scale in the making of a road along a precipitous or escarped coast. Obviously this was done by the action of water, which successively undercut the inclined beds when these plains were under the sea, the shore of which was then at the base of the mountains on the southern margin of the plain. The rocks were then upheaved into their present position. The platforms formed by the quartzite and sandstone beds are always much higher than those formed by the limestone. The plains commence east of Colunga, where, according to Don G. Schultz, the jurassic rocks form the coast. The first limestone platform extends from Riva de Sella to San Antolin; to this succeeds the extraordinary level platform of sandstone, 4,000$^{m.}$ in length, 2,000$^{m.}$ in width, and about 100$^{m.}$ above the level of the sea, which is called the Rasa de Nueva. It is formed by the sandstone beds which cross the river Sella between Margolles and Santianes, where they form lofty and very wild mountains.

Beyond the Rasa de Nueva the second limestone platform commences, and extends itself from the foot of the mountain of Llabres along the borders of Posada, Barro, Celorio, Porrua, Parres, Po, and Llanes. Like that of Riva de Sella, it is uneven and escarped. Towards the E. and S.E. of Llanes another bed of sandstone crosses as before the coast belt, but it does not assume the importance of the Rasa de Nueva; it is also of variable altitude. Then commences the third limestone platform, to the south of which another bed of sandstone forms the platform of Puron. The river of that name cuts through it, and its continuation towards the east is called the Sierra de la Borbolla. When it reaches the coast beyond Santuiste, where the third limestone platform ends, it forms the Sierra de Pimiango, a platform which extends along the coast to the W. of La Franca and Columbres, and an extension of which eastward crosses the Deva and forms the sandstone platform in contact with the nummulitic beds to the north from Columbres, by Unquiera to Pesues. As Don G. Schultz states, this term sierra is applied simply to express the sterile or uncultivated nature of the ground, since the real height of the platform does not exceed 100$^{m\cdot}$, whilst its surface is absolutely level over a length of 12$^{km\cdot}$ from the S. of Acebal up to the river of Tina Mayor, although cut through by the rivers Puron and Santuiste.

Here we have clear evidence of an upheaval of the coast line from a point east of Colunga to near San Vicente, attaining a maximum to the north of Columbres in the Sierra de Pimiango, to the south of which lie the Picos de Europa. The upheaval of this part of the country was accompanied, as the coast line shows, by a series of E. and W. or of N.E. and S.W. faults, the one forming the coast line of the last of the sandstone platforms being distinctly visible along the axis of the valley of Comillas, although in the province of Santander the last upheaval was but very slight. Perhaps the plane of this dislocation extended eastward to Santander, and may explain the cropping out of the lower beds of the jurassic formation in the bay.

The position of these carboniferous rocks, relatively to the nummulitic ones near the Deva, shows that the contact of the two rocks is due to an upheaval of a narrow band of carboniferous rocks along that part of the coast. Otherwise we could not account for the sudden disappearance of the whole cretaceous, jurassic, and perhaps of triassic rocks. In the rise of the whole district between the Deva and the Sella in the Asturias, this band formed the coast and was denuded as it rose. In our section of the Deva we have indicated this by a line of fault north of Columbres. It is probable that another line of fault exists to the south of Columbres, produced by the upheaval of the whole country to the Picos de Europa. This would account for the occurrence of a limestone similar in character to that of the Dobra chain in contact with the cretaceous rocks between Columbres and Alevia, while at the opposite side of the Deva to the eastward, the cretaceous rocks are separated from the Dobra limestone by a considerable thickness of beds. The Columbres beds may perhaps be explained by supposing them to be a mere projecting wedge of the cretaceous and tertiary rocks unaffected by the last upheaval of the coast.

If our view of the relations of the rocks in this district be correct, the Sierra de Cuera, of which the mountain of Alevia forms the eastern part, may be looked upon as the western prolongation of the Dobra range, and must in part be jurassic. The limestone of that range ought to overlie to the westward the rocks forming the coast platform, and ought to underlie the sandstones, clays, conglomerates, limestones, etc., which form the jurassic rocks of Villa Viciosa and Colunga, which is just what is found to be the case. This view also seems to us to simply explain the whole phenomena of the jurassic formation in the two provinces. If we suppose a continuous band of rocks of the formation in question to extend from La Cabada to Villa Viciosa and Colunga, and then the whole country to be upheaved successively but unequally, the country between the Sella and the Deva being upheaved most, and the maximum taking place in this district towards the Deva; further, if we suppose the whole area to be then subjected to denudation, it is quite clear that the portions most upheaved would suffer most denudation. Hence, while at Villa Viciosa and Colunga only the upper jura would be removed, the whole of the rocks down to the Dobra limestone would be removed, and the latter exposed, near the Deva, as in the Sierra de Cuera, while further to the eastward, in the province of Santander, where the upheaval was still less than even at Colunga, the overlying cretaceous and tertiary formation may be denuded only in parts. It is probable that the valley of the Sella was first formed along the meridianal fault bounding the upheaval of the Picos de Europa to the westward, and that the true boundary of the carboniferous rocks is to be sought for along that line.

The curious platforms, which form so characteristic a feature of the coast from Riva de Sella almost to San Vicente de la Barquera, are also found west of Gigon among the palæozoic rocks. So that the jurassic area of Colunga and Villa Viciosa occupies a sort of synclinal between the two lines of platforms, and further confirms the observations just made. The period of upheaval of those platforms must be comparatively modern, because we find not only that the carboniferous rocks were thrown up almost vertically before the platforms were cut out by the action of the waves, but that the nummulitic rocks also were more or less affected by the last upheaval. It would appear that the Cantabrian chain is the result of successive upheavals of the same character, separated by intervals of repose. The last of these produced, as we have seen, the Sierra de Pimiango and other platforms, reaching 100$^{m.}$ in height, previous ones produced the Sierra de Cuera and the Monte Dobra range, the latter being now about 350 to 400$^{m.}$; and so on backwards to the main chain, each upheaval adding, of course, to the height of the previously lifted sierras. During the last upheaval, we may suppose a fracture to have occurred along the Asturian coast, by which blocks, as it were, of the coast gave way, and were thrust up beyond the general horizon of the upheaval. Such an accident would, of course, be attended by sinkings or downthrows along the plane of fracture in the immediate neighbourhood of those upthrows, such as the faults of Comillas Bay and Santander Bay.

We do not propose to discuss what recognized divisions of the jurassic formation are represented by the rocks of Santander, and still less to coördinate them with the series of other areas. To do this would require much further investigation, and the settlement of all the important questions raised in the preceding pages. We may, however. venture to guess the great divisions which a thorough palæontological investigation of the rocks of Santander and of the Asturias may perhaps establish, by a comparison of the fossils which have been already found

In the rocks immediately underlying the dolomite at Comillas, Udias, etc., the following fossils have been found:—*Calamophyllia Stokesii*, Edw., *Diadema subangulare*, Goldf., *Terebratula biplicata*, Sow., *Rhynchonella inconstans*, Sow., *R. concinna*, Sow., *Ostrea gregaria*, Sow., *O. deltoidea*, Sow., *Pecten demissus*, Goldf., *P. cingulatus*, Goldf., *Plagiostoma duplicatum*, Sow. ?), *Pholadomya lyrata*, Morr., *Pholadomya*, sp. undetermined, *Nerinæa Goodhallii*, Sow., *Melania Heddingtonensis*, Sow, *Ammonites Humphresianus*, Sow., *A. Parkinsoni*, Sow., and in some of the lower beds *Gryphæa cymbium*, Lam., *Gryphæa arcuata*, Lam.. *Rhynchonella rimosa*, Buch, *Pecten æquivalvis*, Sow., *Modiola scalprum*, Sow., *Ammonites bifrons*, Brug., *A. serpentinus*, Schloth., and many *Belemnites*. M. d'Archiac gives the following fossils as occurring in the jurassic rocks of Santander, on the authority of Don C. de Prado:[9]—*Ammonites spinatus*, Brug., *A radians*, Schloth., *A Bechei*, Sow. (at Fombellida), *Terebratula*

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[9] Op. cit., t. vii. p. 172.

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variabilis, Schloth. (at Tras la Peña). These fossils appear to indicate the upper lias, and the lower, middle, and upper jura.

The fossils found by Don C. de Prado on the southern side of the chain in the province of Palencia, fully confirm the existence of the lias and inferior and middle jura; the upper jura is, perhaps, covered up by cretaceous rocks, or may be wholly wanting. The following list is given by M. d'Archiac[10] from Becerril del Carpio, Aguilar del Campo, Pozazal, and Bustillo de Santullan:—*Ammonites margaritatus*, Montf., *A. spinatus*, Brug., *A. planicosta*, Sow., *A. bifrons*, Brug., *A. serpentinus*, Schloth., *A. complanatus*, Brug., *A. insignis*, Schübl., *A. Levesquei*, d'Orb., *A. Raquinianus*, d'Orb., *A. Humphriesianus*, Sow., *A. subraditus*, id., *A. niortensis*, d'Orb., *A. Parkinsoni*, Sow., *A. Blagdeni*, id., *A. Gervillei*, id., *A. Martinsi*, d'Orb.; *Belemnites irregularis*, Schloth., *B. canaliculatus*, id.; *Lima gigantea*, Desh., *L. inæquistriata* (?), Münst.; *Pecten æquivalvis*, Sow., *P. desaformis*, Schubl.; *Pholadomya exaltata* (?), Ag.; *Gryphæa cymbium*, Lam.; *Terebratula perovalis*, Sow., *T. Garantiana*, d'Orb., *T. numismalis*, Lam., *T. Phillipsii* (?), Morris, *T. obovata*, Sow., *T. lagenalis*, Schloth., *T. obsoleta*, Sow., *T. plicatella*, id., *T. tetraœdra*, id., *T. rimosa*, v. Buch, *T. inconstans*, Sow., *T. variabilis*, Schloth.; *spirifer rostratus*, Schloth.

No fossils having, so far as we know, been found in the rocks which we have coloured trias on our map, and called so throughout the foregoing pages, the term must be looked upon as provisional. Other geologists have assumed the existence of the trias in the province, and in M. Dumont's map these rocks are brought down low into the Deva. But, except the sandstone near Linares, no such rocks are found upon its course from its mouth to Potes. But we have shown that the sandstone near Linares bears the same relation to the underlying limestone that it does in the Dobra chain to the eastward. Again, Potes would apparently come in upon the trias in the same map; but whether it does or not, the Potes rocks appear, as we have already shown, at El Soto, and at points to the E. and S.E., and must be triassic there in the sense of underlying the jurassic formation. Further investigation may show that the Potes, El Soto, and Pico Jano rocks are older than we have just assumed, and that the trias formation is not at all represented in this region.

In proposing so bold a hypothesis as that of making the highest peaks of the Cantabrian chain, the Picos de Europa, jurassic, we are fully sensible of the very imperfect data, both geognostical and palæontological, upon which it is founded. It is right to point this out specially, because we differ materially about the geology of the district of the Deva with a geologist who has devoted so much time and labour in endeavouring to unravel the complicated geological phenomena of one of the countries in Europe the most difficult to investigate. We would rather have found ourselves in accordance with our predecessors in the same field than otherwise, but as, on coördinating all our observations with those of MM. de Verneuil and de Prado, so far as we were acquainted with them through the work of M. d'Archiac, we found them incompatible with some of those of Don G. Schultz, we had no alternative but to propose some hypothesis which should appear to better explain the phenomena. Our supposition may be found to be incorrect, and perhaps by ourselves first, when this almost inaccessible region is further investigated. In the mean time the hypothesis will have served one of the chief functions of all hypotheses, to show that there is room for further investigation. If we shall contribute to bring about that investigation, we shall consider our labour not in vain.

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[10] Op. cit., t. vii. p. 174.

III. GEOGNOSTICAL RELATIONS OF THE MORE IMPORTANT METALLIFEROUS DEPOSITS.

§. 1. *History of the Mining Industry of the Province.*

The determination of the age, and the stratigraphical classification, of the different rocks of which we have attempted to sketch the leading geognostical features, independent of its purely scientific interest, has also a considerable practical value in connection with the metalliferous deposits of the province, especially those of zinc and lead, which have already brought it prominently before the mining public. The great importance to which the production of the ores of the first-named metal has attained, will justify us in giving a brief notice of the history of the mining industry of the province.

All this mountainous province was once covered by vast forests, of which a magnificent relic still exists near Potes, in the district of Lièvana, already mentioned. Various species of oak appear to have formed the predominant vegetation of this ancient forest, if we may judge by the relic just mentioned, and by their common occurrence in every part of the province. In the neighbouring province of Biscaya, iron ore of excellent quality is abundantly found, the spathose iron of Somorostro being especially celebrated. This ore appears to have been conveyed along the coast to different points in the province of Santander, where the oak forests offered supplies of excellent fuel, and where it was smelted in very primitive furnaces, no doubt similar to the Catalan forges. The existence of those iron works may be traced along the coast in the neighbourhood of the small streams, which flow down from the first or sub-chains, by means of the old slags or "cinder".

The smelting of iron would naturally have drawn attention to the existence of lead ores, and it would appear that such ores as could be procured from the nearer ranges of hills were smelted. Indeed there can be no doubt but that both carbonate of lead and galena were known at a very early period, for we find evident traces of workings for lead ores, not only along the Dobra range, where the galena presents itself at several points at the surface, but also in several of the recently discovered calamine mines. Although, by a confusion of traditions, which appears to be very common in Spain and Portugal, the country people ascribe the origin of all those old workings to the Moors, there can be no doubt that they date from the Roman domination, and perhaps from a still earlier period. This opinion receives strong confirmation from the finding of a coin of the Roman Emperor Aurelian in the old workings at Udias.

It is probable that both lead and calamine were extracted by the Romans, who were well acquainted with brass, though, if any ores were worked by the Celtiberians in this immediate district, they must have been lead, for we have no evidence that brass was known to them. That lead was smelted in the province is proved by the discovery of old furnaces at points where galena crops out in the calamine. They are usually small holes in the earth, of about 30 to 50 centimetres in diameter, and about 20 centimetres in depth, more or less filled with partially calcined fragments of galeniferous calamine, charcoal, and the red burnt clay which seems to have formed the lining of this rude furnace. It has been suggested that, judging from the predominance of the calamine, such hearths may have been employed for the conversion of imported copper ores into brass by means of the local calamine; but, independent of the circumstance that no traces of such ores have yet been found, it is highly improbable, on many grounds, that brass was thus produced directly from copper ores by the addition of calamine.

The smelting of lead ores could not have had attained much development at any time, inasmuch as they are by no means abundant, occurring very irregularly in the lodes, and as they have been always considered to be non-argentiferous. Even now their working is and must continue to be difficult, and but little attractive to the people of a country who set but slight value on galena when not argentiferous. In modern times they have been almost exclusively worked by potters, for glazing their common earthenware. This circumstance has consequently kept up a tradition of their existence, and when the new mining law was promulgated, at the commencement of the reign of her present majesty, Queen Isabella, the facilities which it offered to the public for speculation and dealing in mining shares, were eagerly taken advantage of; and accordingly nearly all the old mines reappeared under new names, inviting the capital and enterprise of the country.

A number of "*pertinencias*", as is termed the standard extent of surface adopted by the law as the area to be included in each concession, and representing a portion of surface $100^{m.}$ by $300^{m.}$, were secured by certain French capitalists in the year 1853, and brought under the notice of an experienced engineer long accustomed to the ores of the country. It was then discovered that the greater part, if not the whole, of those mines, while nearly insignificant as regards their amount of galena, were of immense value in consequence of the quantity of zinc ore which formed its matrix, and which, from its many new and varied appearances, had not, up to that period, attracted notice. Once the public attention was aroused, an incredible number of "claims" were published for different classes of minerals, though chiefly for calamine; but when the fever of the first few years had passed, and a better knowledge of the real value of the ores had been generally acquired, the greater part of the claims were abandoned, and of late years the production of zinc ores for the foreign market has been confined principally to those mines where the great abundance and richness of the ores, joined to good practical treatment and administration, have enabled the proprietors to sustain the works, notwithstanding the continuously low state of the market.

These mines may be classed as follow: 1. Mines of the Compagnie des Mines et Fonderies de la Province de Santander, whose principal works are established at Comillas, Udias, and Florida Mountain, near Celis, besides others of less importance, situated at Ciguenza and Cabada. 2. Mines of the Royal Asturian Company, whose principal works are at Reocin, near Torre la Vega, and Udias; they have besides a few less important "pertinencias" near Comillas. 3. Mines of the Europa Mountains. Some other companies have worked small but very interesting lodes: at Merodio; near Barzena, on the road to Reynosa; in the environs of Novales; in the Dobra range, etc.; but those concessions have produced only very small quantities of ore; as they are interesting, however, on account of the peculiarities which some of them present, we shall include notices of them in the following observations.

A classification according to ownership, however useful for commercial objects, can serve very few purposes in science, and we must therefore classify the different mines to which allusion has been made according to their geognostical relations. From this point of view we may classify them into three principal groups as follows:—

First Group.	**1.**	**Mines**	**of Comillas—Stas. Lucita and Felix, or Venta la Vega, etc.**
	2.	**„**	**of the Valleys of Ciguenza and Oreña.**
	3.	**„**	**of Valley of Udias—*a*, north side—Numa, Esmeralda, Sta. Bartolome, Magdalena, San Roque.** ***b*, south side—Angel de Toporias, Dolores & Rasa mines.**
	4.	**„**	**of Mercadal and Reocin.**
	5.	**„**	**of the Florida Mountain.**
	6.	**„**	**of Puente Arce and of Santander.**
Second Group.	**7.**	**„**	**Dobra range and Viesgo; of Merodio, Tresviso, and the Peñas de Europa.**
Third Group.	**8.**	**„**	**Potes and Reynosa.**

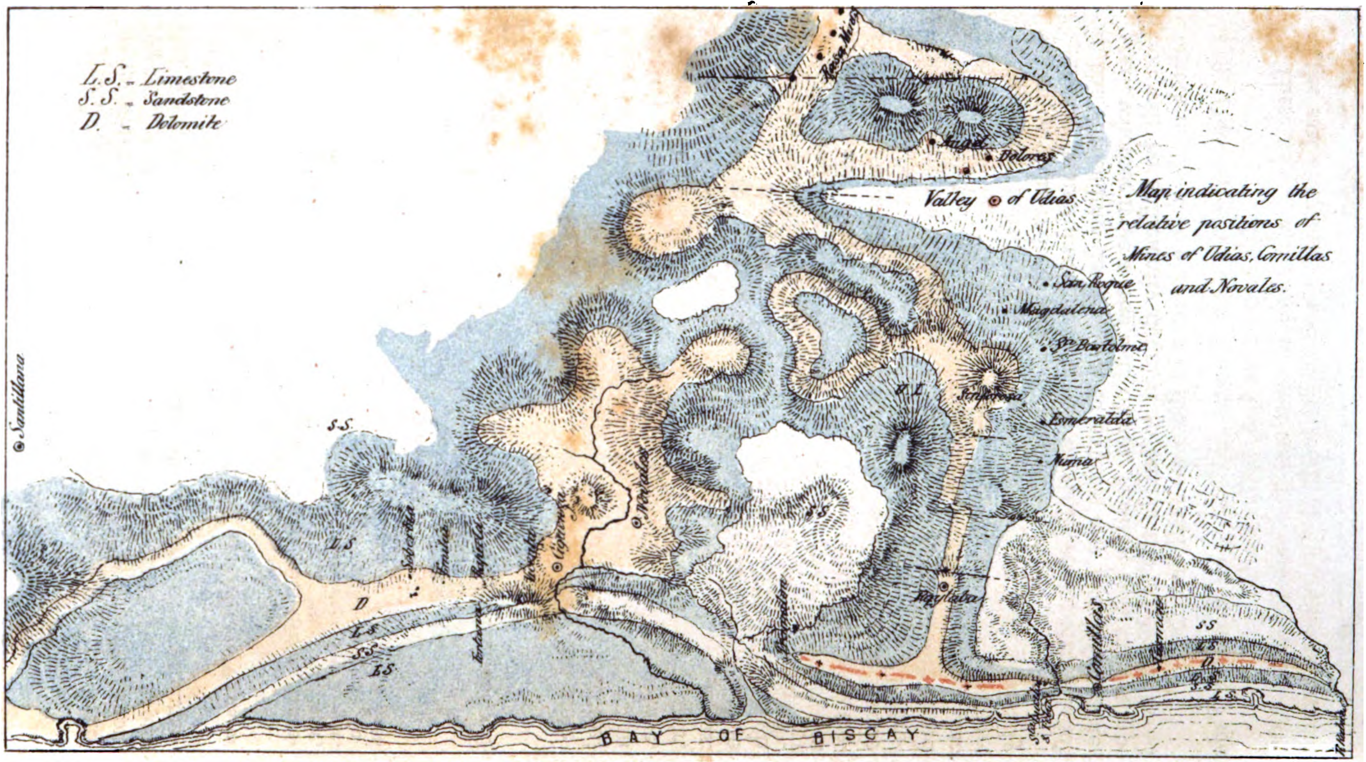
Although we shall minutely describe the structure and mineralogical characters of the ores found in each of the principal lodes in subsequent sections, it will be useful to state here, in general terms, the nature of the zinc ores found in the province. These are blende, Smithsonite, silicate of zinc, or calamine proper, and hydrocarbonate of zinc. The Smithsonite is of two kinds. 1. A white ore which is found associated not only with blende and galena, but also with cinnabar and copper ores, in the high mountain ranges, and not in any of the mines of group I.; 2. a red ore, commonly known as red calamine. The latter is peculiar to the dolomite rocks, of which mention has been frequently made, and is almost universally associated with blende and galena, and sometimes with carbonate of lead. The hydrocarbonate of zinc is a very peculiar ore, and is exclusively found in the limestone underlying the dolomite. The silicate of zinc is found associated both with Smithsonite and hydrocarbonate. Worn and polished nodules of brown hæmatite very generally accompany the red ore and the hydrocarbonate.

It may be useful to state here that we shall use the term "lode" in the succeeding descriptions to express any metalliferous deposit, whether it be a true lode or not, trusting that the description will be sufficiently detailed to enable the reader to avoid mistaking the true character of those we shall describe.

§. 2. *Description of Stas. Lucita and Felix, or Venta la Vega Mines. Plates* 4, 5, 6, 7, *and* 8.

These mines, which really constitute but one, lie about $700^{m.}$ to the east of Comillas, and to the south of the high road which

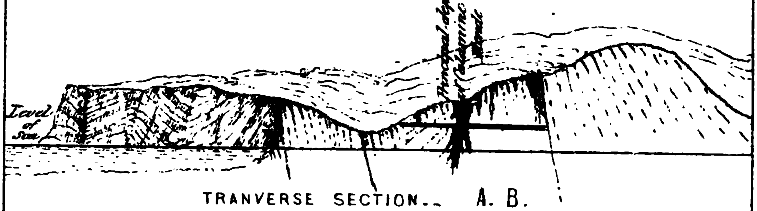
Plate 4.



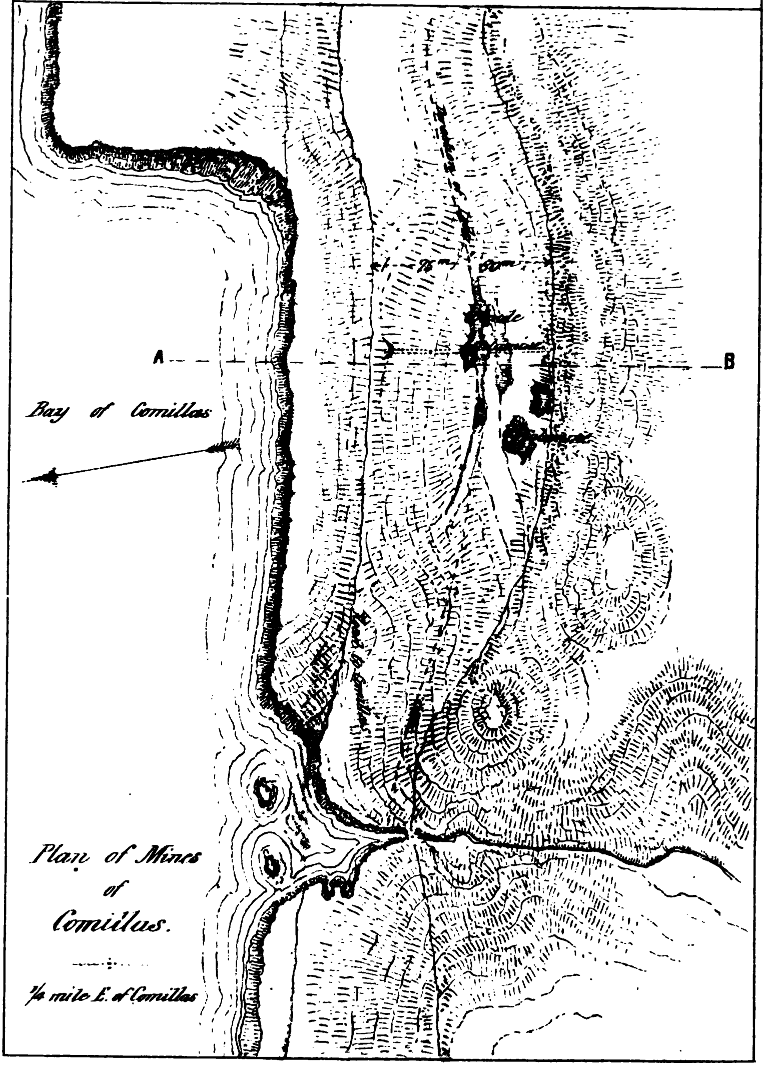
Map indicating the relative positions of Mines of Udias, Comillas and Novales.

L.S. _ Limestone
S.S. _ Sandstone
D. _ Dolomite

Lithographed by G.Bellew. Dublin.



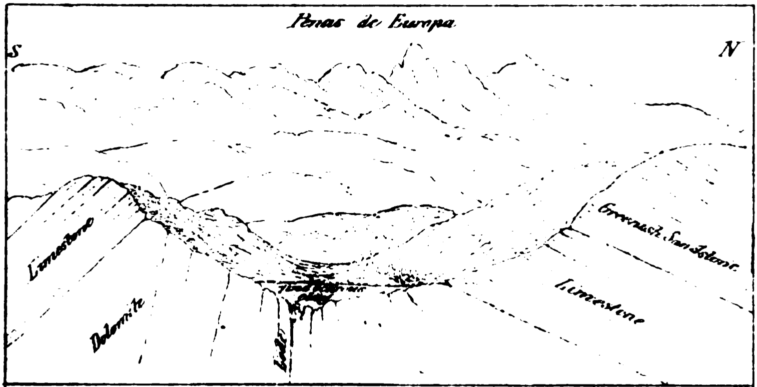
TRANVERSE SECTION.. A. B.



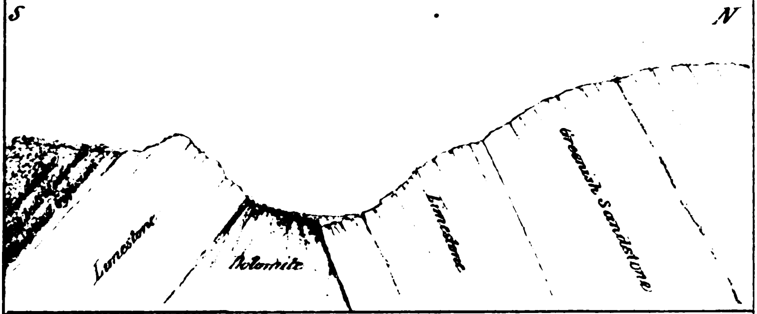
Plan of Mines
of
Comillas.

¼ mile E. of Comillas

PLATE No. 6.



Transverse Section of Valley of Comillas 1/4 mile W. of the village.



Transverse Section of same 1/2 mile W. of village.

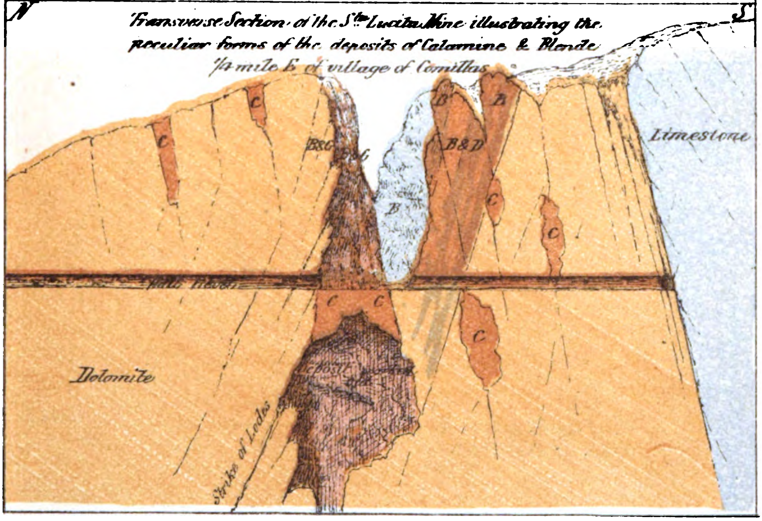
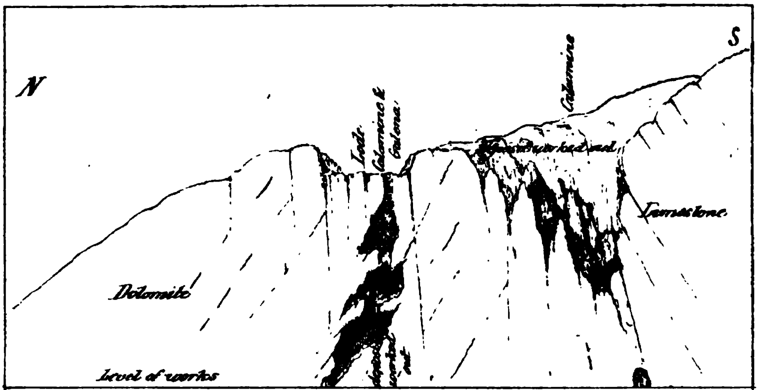
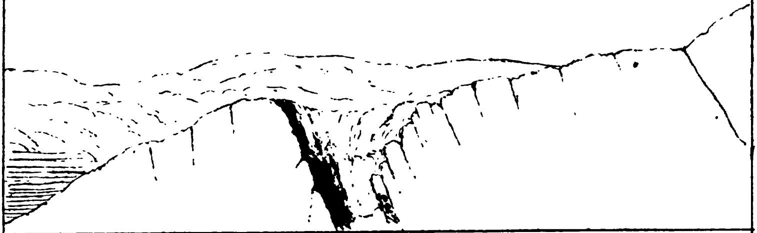

Transverse Section of the Sta Lucia Mine illustrating the peculiar forms of the deposits of Calamine & Blende 1/4 mile E of village of Comillas

PLATE No 7.

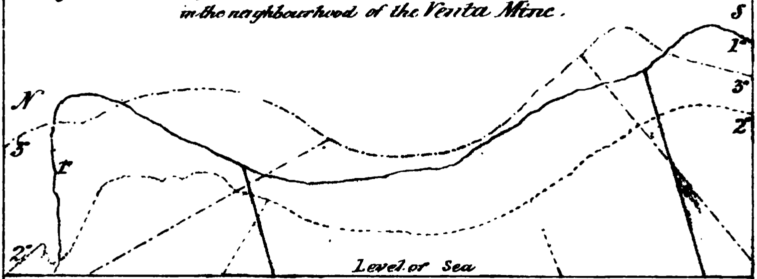


Cross Section of the Venta 40m W. of principal deposit.



Cross Section of the Venta Mine 15.m E. of principal deposit.

Diagram showing the variations of the dips of the Dolomite and Limestone rocks in the neighbourhood of the Venta Mine.



1° Outline ———— Section of Valley at the Venta Mine
2° " ·············· " " " 100.m W. of Venta Mine
3° " —·—·—·— " " " 600, W " " "

Bellews Lithog. Dublin.

winds along the north side of the valley of Ruyloba, a continuation of that of Comillas. Originally "denounced" as a lead mine in 1853–54, its real value as a mine of zinc ore (Smithsonite) soon became apparent, as we have mentioned above. Situated in the immediate vicinity of the village and small fishing port of Comillas, and consequently placed in very favourable circumstances as regards labour and carriage, it was one of the first mines extensively worked in the province.

What may be termed the valley of Comillas, presents very marked characteristics, such as suggest many interesting points in connection with the dolomitic deposits of Smithsonite. Here the observer is struck with the continuity of a strip of dolomite which extends from the Rabia stream to Tramalon, encased on both sides by crests of limestone whose dip can be regularly determined, and thence that of the underlying dolomite. At the two extreme points above mentioned, we find the limestone overlapping the latter rock, and can easily follow the succession of indications of zinc ore, sometimes sufficiently abundant to have justified claims and some preliminary works, and at other points assuming all the importance of mines more or less productive. He may also remark that all the outcroppings present themselves on the south side of the axis of the valley, and that where works more or less extensive have brought to light the peculiar characteristics of the mineralized ground, a fault or slickenside (*plan de glissement*) is always recognizable, running east and west, near which lie the ores, Smithsonite, blende, and galena, and that to the north of this fault, although Smithsonite may be met with, its peculiar characteristics change, whilst blende and galena are always absent.

The superficial earth which covers the dolomite is very ochreous and full of finely polished pebbles of hæmatite, a circumstance which, as we have already remarked, is characteristic of the dolomite rocks throughout the entire province.

Such are the general features of the valley. An examination of the works of the principal mine will add others equally interesting. About 700$^{m.}$ to the east of Comillas, the valley is crossed by a mountain stream Here the dolomite is less tilted up than on either side, the limestone overlapping more. The lode of the Stas. Lucita and Felix mines seems to commence at this point called Puente Portillo. Going towards the east, the limestone rises in dip and uncovers the dolomite, whose maximum of upheaval corresponds with that of a development of ore at a point some 400$^{m.}$ to the east, and called Venta la Vega. The peculiar conditions under which the two rocks occur at this point, have been already described at p. 21, and the cross-section AB, Pl.

5, illustrates them. At about 80$^{m.}$ to the east of the stream already mentioned, the first outcroppings occur, near the contact of the dolomite with the upper limestone. The existence of a principal fault, and of some minor parallel ones, is quite apparent; they are nearly vertical, their dip being to the south. Here blende and galena, and red calamine (Smithsonite) are met with. The dolomite is veined with barytes, which also lines the sides of the principal fault, giving it the appearance of a lode.

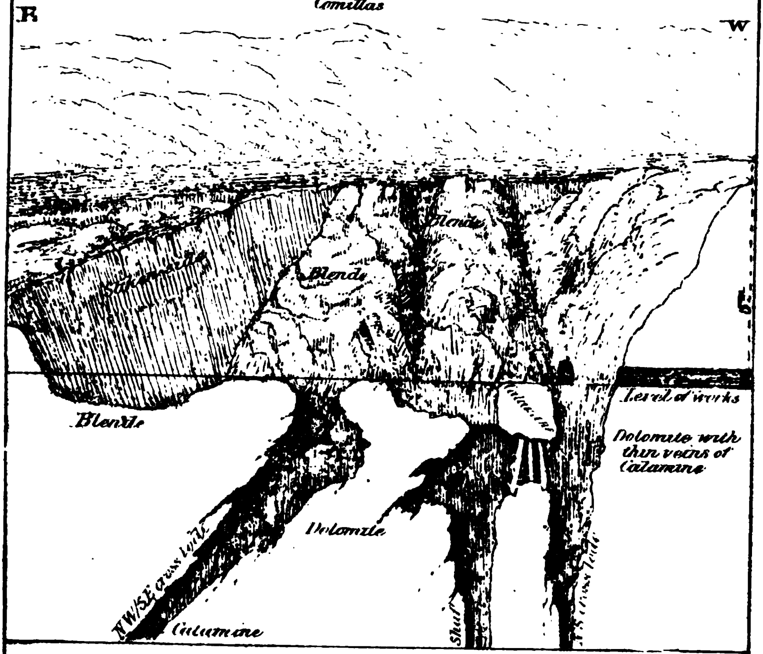
About 60$^{m.}$ farther on, the blende and Smithsonite again crop out, intimately mixed with dolomite in veins of variable, but feeble thickness, and continuet o increase in development up to the principal point, where the great mass of the calamine existed, near Venta la Vega. . At this point two cross courses, or rather joints, occur; the one running north and south, and the other north-west and south-east, the interval between the two on the line of axis of the mine being about 20$^{m.}$ to 25$^{m.}$ That running N. and S. is vertical, while the N.W. and S.E. one dips towards the N.E., at an angle of about 40° to 45° with the vertical.

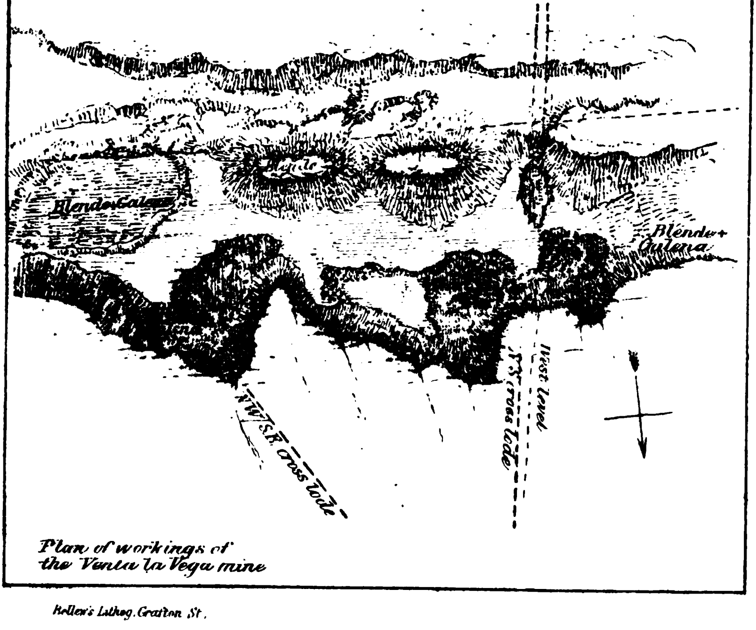
The mine presented originally an immense longitudinal but irregular mass of perfectly pure red calamine (Smithsonite) whose greatest development corresponded to the space comprised between the two cross courses before mentioned. In the eastern and western extremities of this mass, galena was frequently found as if injected into the zinc ore. On the south side blende predominated, the chief part of it still remaining When the works were commenced, the western surface of the calamine had so much the aspect of the surrounding dolomite, there being no apparent break or solution of continuity between them, that few could have recognized the existence of such an immense mass of ore in this particular spot. Galena had indeed been worked for here at some former period, as was proved by the remains of cinder, burnt clay, and fragments of partially calcined galeniferous calamine, found at different joints, clearly the relics of some rude attempt to smelt lead ores. A shaft sunk near the contact of the mass with the dolomite on the north side, went entirely through calamine for 15$^{m.}$, the bottom consisting still of that ore. The whole surface was then attacked, and in the course of the works it was found that the extent of pure calamine (Smithsonite) diminished as the level sank, until, at about 30$^{m.}$ from the surface, or 15$^{m.}$ below that of the principal adit level, the calamine continued to be found only in the two cross courses above mentioned and in the intervals corresponding to the planes of bedding of the dolomite. Towards the west later investigations brought to light some rich pockets, as they were called, at short

PLATE

No. 8

Longitudinal Sect. of Venta la Vega Mine
Comillas





Plan of workings of the Venta la Vega mine

Kellers Lithog. Grafton St.

distances from the main mass, and in immediate connection with the joints or faults already mentioned and with the blende. The peculiarity of those pockets is, that they are entirely isolated in the mass of the dolomite, the only possible communication with the interior being through the generally hermetically sealed fault which corresponds to their vertical medial plane or axis. The ore which they contained was entirely free from galena, or blende, as was also that found in a conically shaped cavity to the south of the main line, and in immediate connection with the overlying limestone.

Shafts have been sunk both to the east and to the west of the main deposit, but without meeting with any important deposit of calamine; frequent indications of galena and blende were, however, met with, thus proving the continuity of the mineralized line.

Some idea of the importance of the principal deposit may be formed when it is understood that from the year 1855 to 1861 the following quantities of ores were raised:

Red calamine (Smithsonite), uncalcined,	12,000 tons.
„ calcined, 28,000=when uncalcined,	37,000 „
Blende,	3,500 „
Picked galena,	35 „
Total uncalcined ore,	52,535 tons.

These numbers are rather under than over the exact quantities of ore raised.

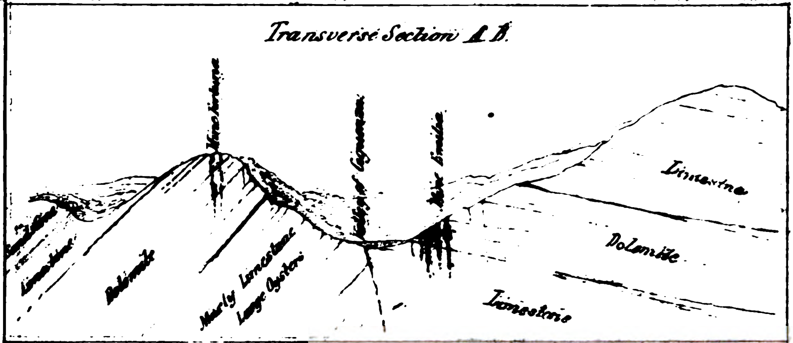
From the preceding observations it results that the Venta may be described as an "irregular lode" extending all along the south side of the valley of Comillas with a nearly vertical dip, but only attaining a highly developed mineralized state at the venta, where the upheaval of the dolomite seems to be at its maximum; that the main line, well marked by the existence of an original joint or fault, is characterized by the presence of small quantities of blende and galena, and by barytes, whilst to the north and south of the main line, no sulphides or barytes occur; that a system of cross courses or joints running north-west and south-east are distinguishable, and apparently having a direct relation with the mineralized points, and a certain connection with the general direction of the transverse valleys which meet that of Comillas, the points of intersection generally showing alterations in the general bearing of the beds; finally, that the very great tilting up, which the dolomite seems to have suffered, in conjunction with its peculiar physical characteristics, being extremely broken and loose textured, may in a great measure explain the irregularities of the lode, and account for its incomplete study.

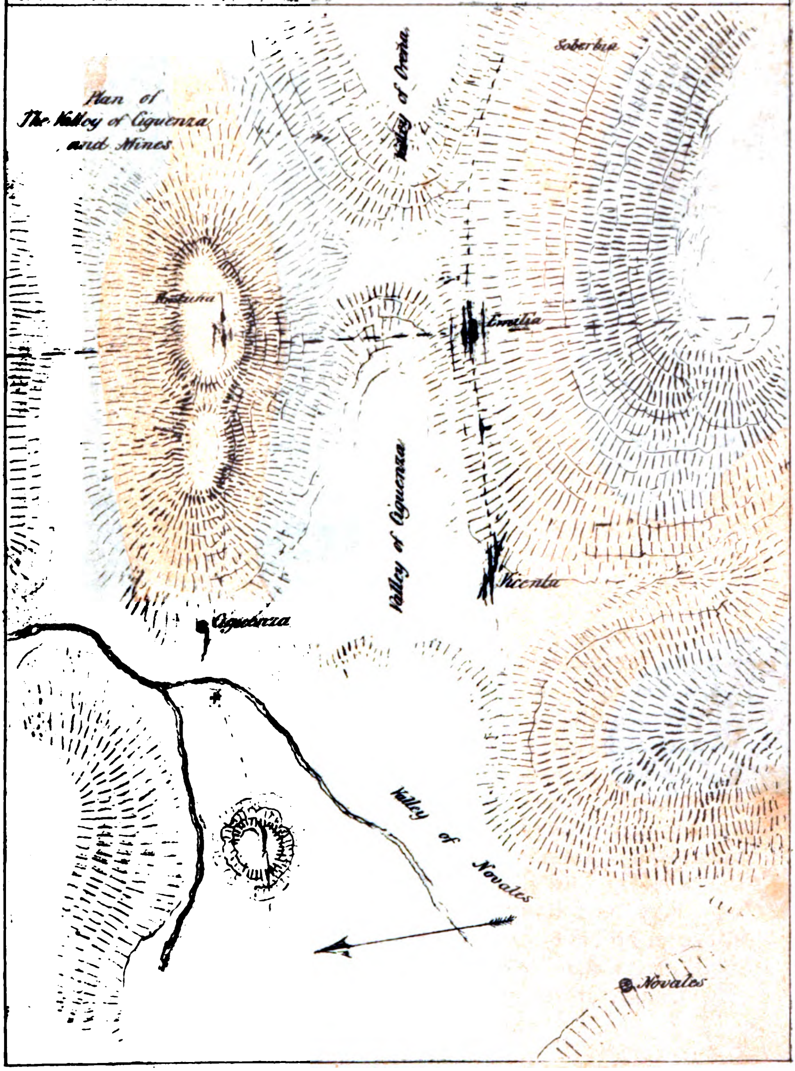
§. 3. *Description of the Mines of the Valley of Ciguenza. Plates* 4, 9, *and* 10.

When describing the transverse section of the map HK, *ante*, p. 31, the mines situated in the valley of *Ciguenza*, near Novales, were noticed. Their connection with those of Comillas on the one hand, and with the group of Udias on the other, is very interesting, many reasons tending to show that they all belong to one and the same system of deposits. On examining the plan, Pl. 4, the connection will appear more distinctly, especially if the valley of Comillas be followed up to Tramalon. Here the dolomite is covered over by the overlying limestone and sandstone rocks, which present at this point the same anticlinal as has been already indicated when speaking of the whole valley, the dip of the rocks being, however, greatest and most marked on the northern side, where the high road passes. On one side of the road, where it winds down the side of a narrow encased valley, in the bottom of which runs a stream which flows into the sea, forming here a sandy inlet, the upper beds of the limestone overlying the dolomite crop out. In some places the beds are nearly vertical or dip at a very high angle to the north, and in one of them abundant specimens of *Pecten nitidus*, Mant., have been found. Thin beds of blue clay occur in the overlying sandstone, and in them are found seams of lignite full of iron pyrites, and which characterize this formation all along the coast of Santander. Traversing the valley already mentioned, and passing through the village of Cobrecez, whose orange groves crown the opposite heights, the dolomite beds are again met with, cropping out from under the limestone of the neighbouring mountain, and covering the whole of the bottom of the encased valley of Novales. Here numerous indications of ore occur, but more particularly on the western, eastern, and northern sides. Along the last-mentioned side the indications of calamine may be traced from near the limestones on the west, up to the village of Ciguenza, and to the neighbouring valley in which are situated the mines Vicenta and Emilia.

This narrow valley is about 750$^{\text{m.}}$ in length, from opposite the village of Ciguenza to the saddle which divides it from that known as the valley of Oreña. The breadth between the summits of the opposite hills is about 650$^{\text{m.}}$ to 700$^{\text{m.}}$ along the line indicated in the plan, Pl. 9. The outcrops on the southern side may be followed for more than 1000$^{\text{m.}}$, beyond which, although probably extending much further, it is difficult to trace their connection in consequence of the nature of the ground. The trough of the valley is occupied by a deposit of highly

Plate No 9





Bellew's Lithog. Dublin.

ochreous clay, abounding in the polished nodules of hæmatite, to which allusion has been already made, and strikingly resembling those of Reocin. On the south side the beds of dolomite are almost horizontal, while on the northern they dip at an angle of nearly 45°, a circumstance which suggests the existence of a fault in the axis of the valley, by which an upthrow of the underlying limestone beds that crop out here in a remarkable manner as well as in the neighbouring valley of Oreña, was produced (see transverse section AB, and plan of the valley of Ciguenza, Pl. 9).

The dolomite on both sides is highly fissured by vertical joints running E. and W., and presenting on the southern side a remarkable continuity. Three or four principal ones pass at the points indicated on the plan, Pl. 9, as the mines Vicenta, Emilia, and Soberbia, and being there enlarged and filled with ores, constitute the mines just mentioned. Of these, the two first are very interesting, both on account of their structure and the peculiar ores found in them.

At the Vicenta the joints or fissures present themselves more favourably for investigation, in consequence of a cross valley here interrupting them, and allowing of their being opened under very advantageous conditions. Three principal joints were thus worked; but other parallel ones remain still uninvestigated. They are nearly vertical, and irregular in breadth, sometimes attaining two metres, which in direction or in depth diminishes until the joints become mere planes of contact. The filling matter is generally a light, spongy, very plastic, hydrated ochreous earth, giving way very easily, and presenting in many places such a close resemblance to the enclosing dolomite in its jointing and general physical appearance, as to suggest that it was produced by the decomposition of that rock *in situ*. In the wider joints, and in the medial plane of this earth, was found a thin rib of red calamine, generally highly charged with oxide of iron, and in many cases passing insensibly into an ore of iron. In other joints the ore at the surface was composed entirely of reniform or stalagmitic pyrites; in descending, this ore gradually became associated with blende, the two ores forming two thin parallel ribs in close contact, which, lower down, passed into massive calamine, that filled up the whole interval between the two dolomitic walls; gradually this thinned out as the walls approached, and ceased altogether where they came in contact.

In other joints, again, no calamine was found, the filling up matter being merely earth and oxides of iron. The calamine was more abundant in the joints towards the south than in those nearer to the level of the valley. Some galena was found associated with the blende and oxide of iron, but in very limited quantity.

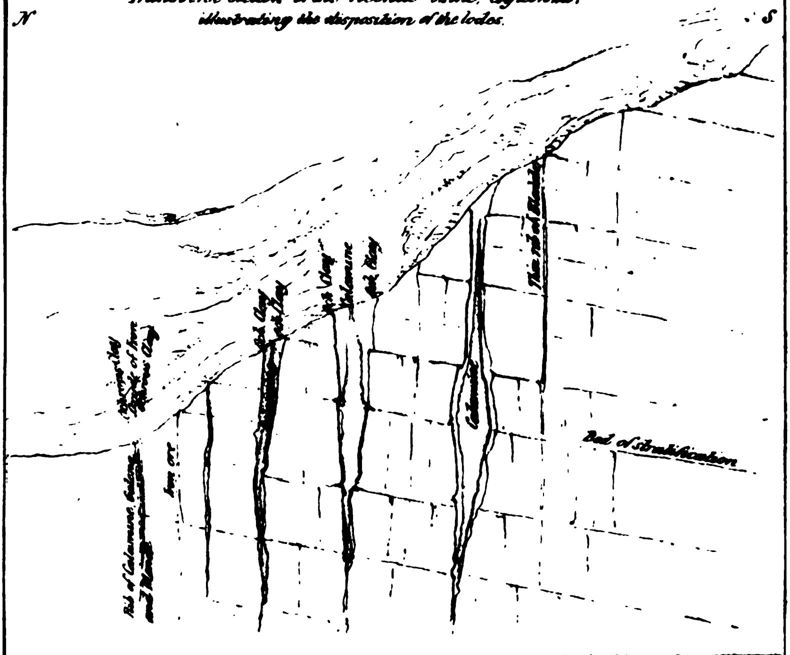
The joints described were crossed in a most marked way by a cross course, running nearly N.W. and S.E., and which seemed to have been posterior to the jointing, as the intervals between the successive fissures appeared to have each suffered a dislocation or downthrow towards the west. This cross course was in some places $2^{\mathrm{m}}{\cdot}5$ to $3^{\mathrm{m}\cdot}$ in width, the points of intersection with the main joints presenting the largest cavities, but not consequently the most mineralized portions of the deposit.

Along the southern side a number of elementary lodes, consisting of a plane of fracture between two thin ribs of barytes, and containing no indications of ore, may be observed. They may be traced from this mine along the rough and uneven surface of the weathered rock, up to the Emilia mine, mineralized points being noticeable, however, in the interval. At Emilia the joints present a new character, that of being mineralized without containing the remarkable quantity of ochreous earth found at Vicenta. The ores, too, are different, blende, Smithsonite, and a comparative abundance of galena, being found. The dolomite has also a different texture, being here harder, sometimes coloured of a dark gray or black, highly crystalline, and so intimately associated at some points with blende, that the passage from pure blende to pure dolomite becomes quite undistinguishable to the eye. When broken, the faces of incipient jointing are found coated with bitter spar crystals, which are also found lining the geodes or druses which occur in it. An abundance of these crystals of bitter spar is, indeed, characteristic of this mine. This mine was first worked for galena; but when afterwards the calamine was found to occur abundantly, it became equally important as a zinc mine; the ores are, however, very much intermixed. They generally occurred in the joints near where they cross the planes of bedding. Some of the joints being more open, presented at the surface, when uncovered, a mixture of galena and calamine (Smithsonite), a thin layer of fine plastic brown clay separating the ore from the walls; this clay at certain points, usually in close proximity with bunches of galena, became more abundant, and of a yellow colour, the texture remaining, however, the same. Holes or cavities frequently occurred in the planes of bedding, filled with this earth: these were discovered in the course of the work, by the removal of the blocks of rock between two neighbouring joints.

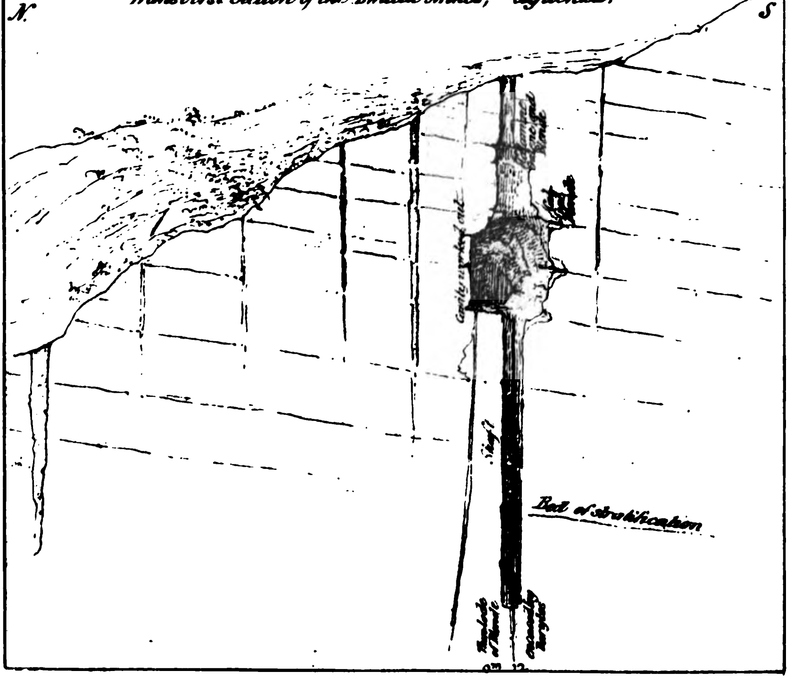
An examination of the transverse section of the Emilia mines, Pl. 10, will show that the principal mass of the ore seems here to have been situated at one particular point about 12 · below the

Plate No. 10

Transverse Section of the Vicente Mine, Giguenza, illustrating the disposition of the lodes.



Transverse Section of the Emilia Mines, Giguenza.



Bellows Lithog. Dublin.

surface, and to have, in fact, occupied in reality the place of so much dolomite removed, some of the ore extending itself on the south side for about 40 to 50 centimetres between some of the planes of bedding. To the north a joint, lined with a thin film of the clay already mentioned, formed its boundary, while to the south the penetration of the dolomite was so complete in some places, as to render the determination of the limit between the two so difficult, that the quality of the ore was the only practical means. The blende here occurred in the jointing, rarely in the planes of bedding, and was secondary in point of development. The length of this particular deposit was about $10^{m.}$, its breadth about $4^{m.}$ at the bottom, and the height about $5^{m.}$ A plane of bedding terminated this caries of the rock in depth, while the mineralized joints still continued downwards, in one of which a shaft was sunk, which showed that it still presented the elements of a lode on its eastern and western sides, a thin rib of blende, encased by barytes, being quite distinct, while the joint itself continued uniform and served to guide the works. The dolomite was here very hard, striking fire continually with the tools, as would a quartz rock—a character more or less common to all the dolomite of the province, particularly in the mineralized districts.

The works extended by a level to the east and west of our plane of section, following the planes of jointing, and exhibiting a more or less continuous lode of galeniferous calamine, with associated ochreous earth, along a distance of 50 metres. Transverse galleries of $5^{m.}$ to $7^{m.}$ to the north and south, indicated fully the existence of ores in the neighbouring joints, although not always in such abundance as to warrant mining operations.

At about $30^{m.}$ to the north of the works of the Emilia, and somewhat below their level, some joints were opened in order to seek for calamine. None was met with, however, but hæmatite was found to fill up the whole fissure. The same ore again occurs at about $500^{m.}$ to the east of the Emilia, where the works constituting the Soberbia mine are situate. The oxide of iron is here associated with reniform pyrites, the ore strongly resembling in many respects that found at Mercadal.

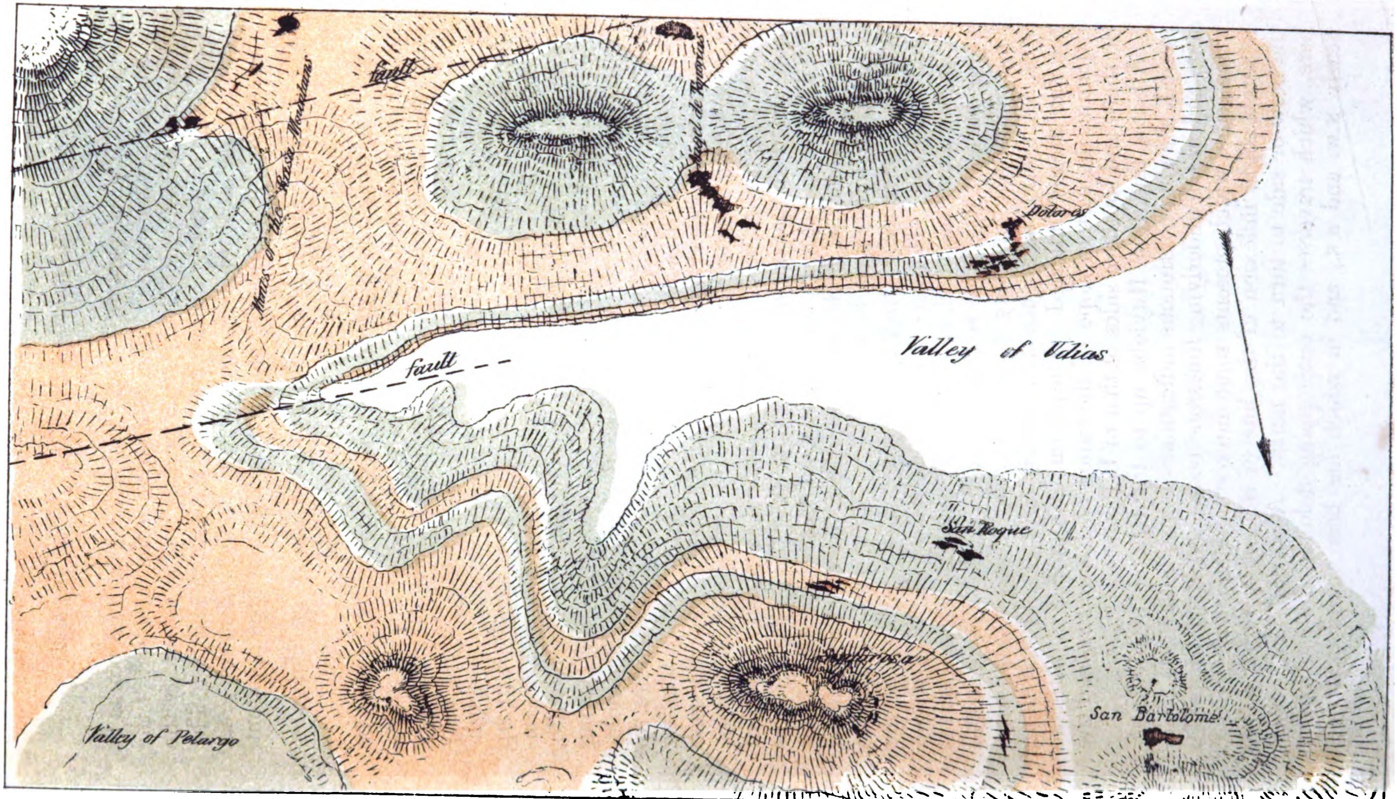
The ores worked at the mine "Fortuna", situated on the summit of the bold hill forming the north side of the valley of Ciguenza, occur under conditions somewhat similar to those described when speaking of the Vicenta mine.

Numerous indications of calamine and blende occur in the western side of the valley of Novales, in the dolomite, whose fissures are mainly filled up by the ochreous earth already described, and which here constitutes the soil. Those indications may be traced up the side of the encasing mountain towards the south-west, and have become sufficiently important at certain points to constitute mining claims. This continuity in the direction of the Udias mines presented such striking features as to justify the supposition of a direct connection existing with the latter. The question has not yet been completely studied; but its great interest, both geognostically and industrially, is at once apparent.

§. 4. *Description of the Mines of the Valley of Udias. Plates* 4, 11, 12, 13, *and* 14.

In examining the plan of the valley of Comillas, it may be remarked, that a cross or transverse one occurs at Ruyloba, following which, the dolomite may be traced on continuously to Udias. The dip of the beds at the beginning of this valley is towards the east, and is low. In the immediate neighbourhood of Ruyloba, a fault occurs which throws them up to about 25° to 30°, giving rise thus to a ridge which continues in a southerly direction to a point called Peña Castillo, where another fault occurs, running E. and W., and leaving the beds with a dip of about 25° towards the east. The dolomite rock continues to crown the hills all along this ridge up to the valley of Udias, the north side of which it follows, tending however to disappear underneath the overlying strata to the east. At the extreme eastern angle of the valley another fault occurs, which tilts up anew the strata, producing thus the tongue of mineralized ground on which are situated the Angel de Toporias and Dolores mines. Further to the south, the strata are again tilted up by another fault, which determines thus the formation of the Rasa hills, in whose dolomitic rocks the most productive calamine mines exist; they are also the most southerly of the Comillas group. Here the dolomite meets the valley of Cabazon de la Sal, along the north side of which it may be traced until it passes beneath the Saya river towards the east. The over and underlying limestone may be concurrently traced up from Ruyloba, and their concordance with the dolomite observed all along the line already indicated. They form, in conjunction with the dolomite, the eastern slope of the valley of Ruiseñada, and the northern and southern sides of that of Udias.

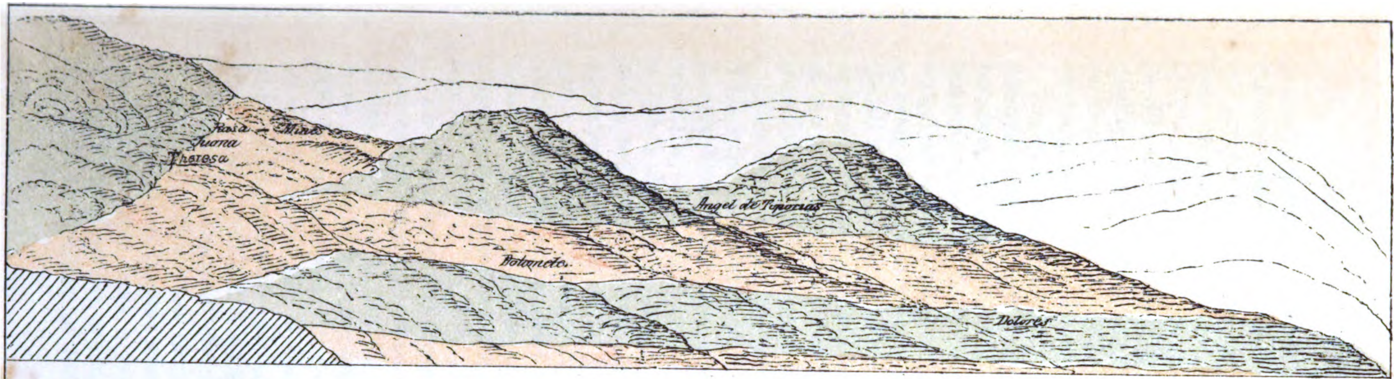
All this line, from Ruyloba up to the Rasa, is highly mineralized, showing continuous indications of ores, both in the dolomite and in the underlying limestone beds. At Ruyloba itself a lode occurs, which presents some interesting characters. There is here a slight inflexion of the line of the ridge, which causes the brow or side to turn to the north. A vertical fault occurs here, which traverses the outcropping dolomite in a direction nearly N.W. and S.E., and in which has been found calamine,

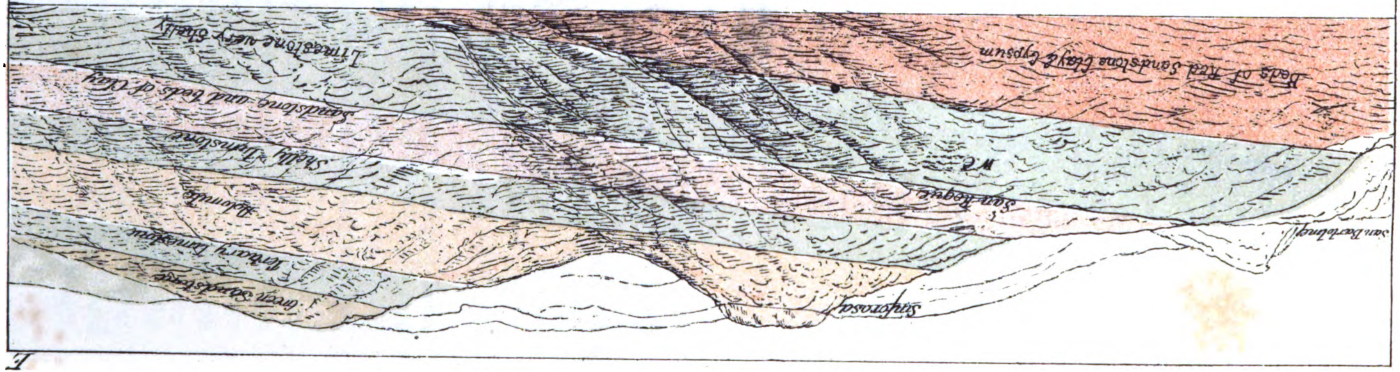


Lithographed by

G.Heller Dublin

General view of South side of valley of Vilias





General view of North side of valley of Vilias

generally intimately mixed up with blende and very finely granulated galena, the mixture being so intimate as to have rendered the greater part of the ore extracted worthless. The width of this fault or lode is variable, but may be estimated at from 2$^{m.}$ to 3$^{m.}$ The blende has many of the characteristics of that of the Florida mines, as shall be noticed hereafter. On account of the quality of the ore, no serious investigation has been undertaken in depth; but a natural shaft, seemingly some former water-channel, indicates a probable continuity.

Indications of blende and calamine occur along the line of dolomite towards Udias up to near Peña Castillo, in the neighbourhood of which the first deposit of white calamine (hydrocarbonate) occurs in the Numa mine. The peculiar relations of the limestone and dolomite beds has been already indicated, as well as their connection with the two classes of ore, red and white. As all the deposits of white hydrocarbonate and silicate are more or less alike, it will, perhaps, be sufficient to describe one or two of the more important ones in detail, and merely notice the special peculiarities of the others.

The first which we propose to notice is the Esmeralda. This mine is situated in the limestone, which crops out immediately from under the dolomite; on the northern side of the works a fault running E. and W. is quite perceptible, near which a shaft was sunk in search of white ore. At a certain depth red calamine, accompanied by galena, was found, by which a connection seems to be established between the two classes of ore. A similar circumstance may also be noticed at the San Bartolome, the next white mine which occurs, following up the limestone towards Udias, and one of the most interesting both as regards its ores and the peculiar conditions under which they are found.

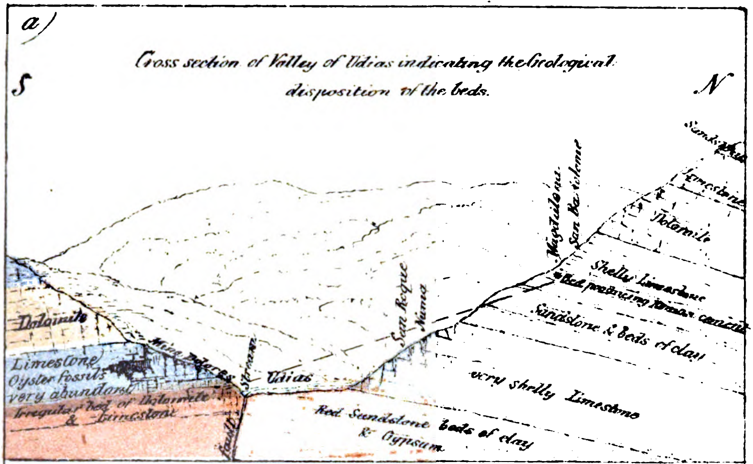
The San Bartolome deposit is situated at the flat summit of a spur of the limestone rocks, near the N.W. angle of the valley of Udias. To the S., the W., and the N., depressions occur which have allowed of its being attacked at the latter two sides, at about 30$^{m.}$ below the level of the outcropping. At the top, the cavity in which the ore lies is about 50$^{m.}$ in length, and 25$^{m.}$ at the point of its greatest breadth, near the eastern extremity; the walls incline in towards the axis, giving to the cavity a conical or funnel shape, characteristic of all those limestone deposits. Points or needles of limestone, having the appearance of immense truncated stalamites, become more frequent as depth is reached. The walls themselves have a smooth surface, such as would be produced by tidal action, when boulders or gravel are rolled to and fro upon the surface of rocks. The cavities resemble, in fact, very much those deep holes or wells which may be met with along limestone shores, where the beds are horizontal or but slightly inclined.

In such a cavity was formed an immense mass of white calamine, although under conditions so extremely variable that it would be difficult to define them. Some idea would, however, be formed of its structure by supposing a large conically-shaped cavern to have existed, and in which stalactites were formed by solutions containing carbonates of lime and zinc; if, then, we suppose the whole of those stalactites to be broken up by the falling in of the roof, or some such similar accident, so as to produce a confused mass, which new solutions again covered with repeated crusts of carbonate of lime or hydrocarbonate of zinc, the result would resemble somewhat the appearance which this deposit presented. Such, too, may have been the mode of its formation, and the green ochreous and plastic earth in the western part of the deposit may have been carried by floods into the cavern. Lumps of carbonate of lead have also been found in the clay just mentioned, and the existence of ancient inclined galleries found in this part of the work, leaves no doubt that the mine was once worked for that ore. The bracings were of oak, worked with the hatchet, as were also the boardings, and had a striking resemblance to the similar works found in the mines of Welkenrath, near Aix-la-Chapelle, one of the groups of the Vieille Montagne Company's mines, except that the boarding was there sawn; in this mine the ore sought after was the galena which accompanies the calamine, and also blende, pyrites, and oxides of iron. The direction of the galleries was irregular, having seemingly followed the sinuosities of the ore sought after, their section being small, not exceeding $0^{m}\cdot80$ in the square. Some idea of their age may be formed from the fact that the oak had become entirely black and extremely hard, having all the appearance and solidity of Irish bog-oak.

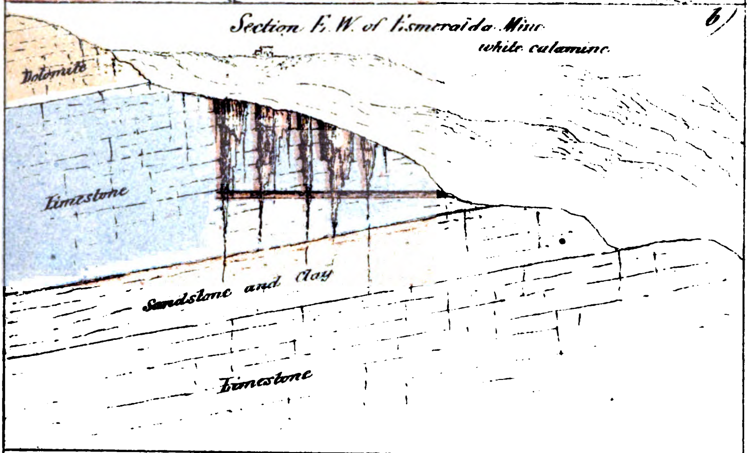
An adit level was driven from the north side, where the ravine sinks enough to have enabled it to meet the principal shaft at about $30^{m.}$ from the surface. In driving it a deposit of red calamine was cut through, which was rendered still more interesting by the presence of galena and blende. This deposit seems to have formed a lenticular mass, no trace of it existing at the surface, while near it was found a fault or rent in the limestone, running E. and W., and communicating with the surface, which had momentarily impeded the works by letting down a large quantity of earth. The red calamine may be supposed to occupy a cavity situated on such a rent or fault. None of the faults peculiar to the dolomite, and marked by slickensides, are appa-

PLATE No 13

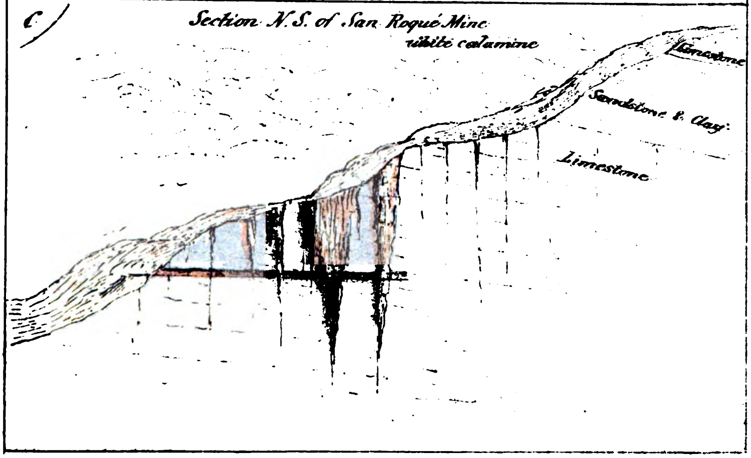
a) Cross section of Valley of Udias indicating the Geological disposition of the beds.



b) Section E. W. of Esmeralda Mine white calamine.



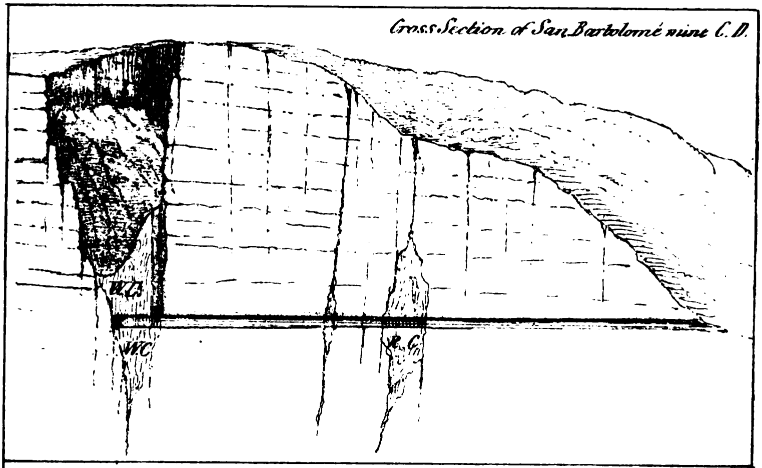
c) Section N. S. of San Roque Mine white calamine



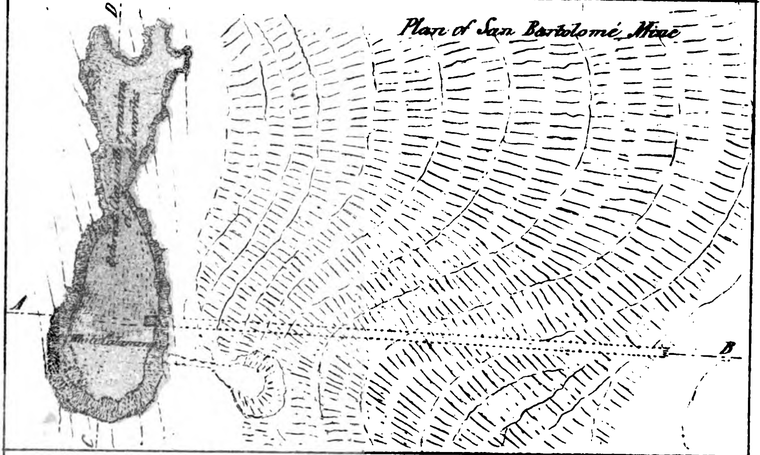
Lithographed by G. Bellew. Dublin.

PLATE No. 14

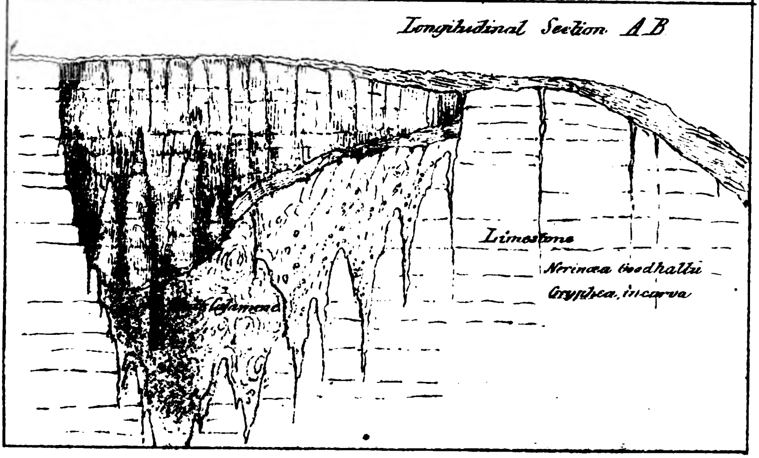
Cross Section of San Bartolomé mine C. D.



Plan of San Bartolomé Mine



Longitudinal Section A B



Bellew's Lithog. Grafton St.

rent in the limestone. Vertical joints, on the contrary, characterize this rock, and those, when widened out, and filled with white calamine and earths, constitute the mines Numa, Esmeralda, Magdalena, San Roque, and Dolores. In the case of the Numa and San Bartolome, those enlarged joints form conically-shaped caldrons, whilst at San Roque, Magdalena, and Dolores, they have an elongated, zig-zag shape at the surface, but, on the whole, presenting nearly the same general characters, as may be seen by examining the sections *b* and *c*, Pl. 13, and the sections CD and AB, Pl. 14.

Leaving the north side of the valley of Udias, where the mine Magdalena is worked in the limestone underlying the dolomite, and which produces hydrated white ores, but sometimes charged with ochreous clay, and the San Roque mine, situated in the same bed of limestone as the San Bartolome, and having many of the characteristics described as peculiar to the latter, and also yielding the same kind of ore, we pass to the south side, where are situated the Dolores mine, the Angel de Toporias, and the whole set known under the general title of the Rasa mines. Allusion has already been made to the first mentioned in describing the beds of the valley of Udias.

The limestone in which the Dolores occurs, and which dips here about 10° to 15°, would correspond with that of the Magdalena on the north side, and although nearly horizontal in its bedding, is nevertheless highly fissured by vertical joints. The rock itself, which, from the fact of its furnishing a cement, must contain a certain amount of silicates, would seem to have offered but little resistance to the decomposing agents which came into contact with it; and in some such decomposing action would probably be found an explanation of the extent and frequency of those large fissures, which correspond not only to the planes of jointing, but also to the planes of bedding. In both have been found characteristic hydrocarbonates and silicates, some of them even presenting a peculiar gray colour, indicative of that of the rock in which they have been found. The regularity and frequency of the joints nearly vertical to the planes of stratification, have given to each bed the structure of a massive pavement, in which a block gives way if not directly sustained by the subjacent bed. This dislocated structure, aided by the activity of the decomposing agents, would not only facilitate the enlargement of the joints and the formation of cavities, but also of caverns. Such a result has already been partially indicated, when offering some explanation of the peculiar structure of the San Bartolome mine; here, however, we have another form which perhaps completes the explanation. In the upper part of this limestone at a point near the plane of contact with the dolomite, a shaft was sunk in search of beds of calamine, and a depth of about $10^{m.}$ to $12^{m.}$ had been reached, when the workmen came upon a cavern until then completely isolated, and which must have evidently resulted from the action of a stream of water upon the easily decomposed rock. Its resemblance to the mine, or, as we may for a moment term it, the open cavern of San Bartolome, was completed by the presence of masses of white ore. At the northern end, or that nearest to the surface, a small mound of fine surface earth was found, which appeared to have gradually been formed by the continual falling in of particles through a funnel-hole, corresponding in all probability to a plane of jointing, and consequently forming the orifice of a nearly vertical passage to the surface. Not far from this mound of clay were found a number of fossil remains, some lying on the floor, and others partially buried in the ore which covered it. At the period of its discovery the orifice was sealed up. Probably this occurred by one of the blocks of limestone getting detached from its place by the corrosive action already alluded to, and falling into the passage, suddenly shut it up, and thus enabled the most singular chemical changes to go uninterruptedly on for ages. The first fossils brought up by the workmen who discovered the cavern, consisted of part of the antler of a deer almost unchanged, and some bones, among which were conspicuous three teeth of the *Elephas primigenius*, two of the under jaw being wholly unchanged, and one of the upper jaw decomposed into lamellae, of which several adhered together. As soon as the discovery of this cave became known one of us (Mr. O'Reilly), in company with M. Javot, the head engineer of the mines, at once visited the spot. On descending into it, the visitors were struck by the appearance of the roof and floor; from the former descended stalactites of various sizes and of the most fantastic forms, the more common being that of an elongated, inverted cone, like those met with in limestone caverns; many, however, had the appearance and colour of white coral trees, and some being almost pure hydrocarbonate of zinc, were of the dazzling white peculiar to that mineral. The floor was composed of one immense bed of white ore of variable thickness, but in some places it was found to attain a thickness of $1^{m.}5$; the irregularity of the ground producing a corresponding irregularity in the surface of the bed. Traces of a stream were recognized, which during the rainy season traverses the cavern, and which no doubt contributed to the deposition of the hydrocarbonate of zinc. The floor was so white that the visitors hesitated to tread upon it with their muddy boots. Here and there the floor was covered with the mineral in a granular form, and portions of it, upon which water was continually forming, felt soapy. The phenomena presented where the dropping occurred are very interesting, for they give us an example of one of the modes of the production of globular structure so complete, that we can trace it through every stage. As we have had occasion to trace the development of reniform structure in an equally complete manner, we propose to devote a separate section to the mineralogical description of the ores of the province, to which we accordingly refer the reader for a full account of the effects of the dropping water in the structures of the Udias cave.

During a second and more extended visit to the cavern many other fossils were found, among which were portions of the tusks of a rhinoceros. The section was oval, 2½ centimetres by 4½ centimeters, diminishing to 2½ centimetres at the extremity, and about 20 centimetres in length, and slightly curved; and a tooth 2 centimetres in diameter, and 3½ in height, of some carnivorous animal. The tusks were decomposed, and became very friable when exposed to the air. A fragment of a large bone, apparently representing the acetabalum, the hemispherical cavity intended for the reception of the head of the femur being 15 to 16 centimetres in diameter, and having a depth of at least 8 centimetres; there were also some ribs, small femurs, apparently of deer, and the bones of birds. About forty specimens were collected by the care of M. Javot, head engineer of the mines, with the intention of sending them to the Museum of Paris, accompanied by descriptive notes. The governor of the province, however, having heard of the occurrence, requested the company to whom the mines belonged, to hand them over to him for the purpose, as was understood, of having them preserved for the public in the museum of the School of Mines at Madrid. The directors of the company at once acceded to the request, and the fossils were in consequence removed by the alcalde of one of the neighbouring jurisdictions, before even those who found them had sufficient time to attentively examine them.[11]

Between Comillas and Udias the dolomite already described contains some outcroppings of red calamine, which, however unimportant commercially, are nevertheless interesting on account of their connection with the white ore deposits already mentioned. From near Peña Castillo indications of ore may be met with and followed up to a hill about 1000$^{m.}$ to the S.E.: here they increase and have assumed sufficient importance to be worked as the mine Sinforosa, which however has been but feebly productive. White calamine has, however, been found in the fissures of the underlying limestone. It is only on the southern side of the valley of Udias that the red ore mines assume a real importance. Two groups may be distinguished, those of the Gandara (the name given to the south bank of the valley), and those of the Rasa, situated on the continuation of the dolomite towards the valley of Cabazon de la Sal. Of the former the more important are the Angel de Toporias and a portion of the Dolores mine.

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[11] Mr. O'Reilly having had occasion to pass through Madrid in the month of April, 1862, and being most anxious to see the specimens, and learn the result of the investigations of the professors of the School of Mines, was surprised to learn that no such collection had ever reached them, and that they had not even heard of them! It is to be hoped, however, that such an important scientific treasure is not entirely lost, and that the efforts of the learned director of the School of Mines will be successful in finally securing the collection for the public, for whom it was originally destined.

The Angel de Toporias was at first claimed as a lead mine, but subsequently its great apparent wealth in calamine rendered it an object of the rival claims of the two most important companies in the province. As may be seen by the map, Pl. 4, it is partially covered by a strip of the overlying limestone which forms two conical hills on the south side of the valley of Udias, dividing it thus from that of Toporias. In this latter valley the dolomite crops out from beneath the limestone, and contained a very rich deposit of calamine, now exhausted. The works extended from near the Dolores to the valley in question, passing under the limestone hills at a depression which occurs between them. The ore here, as at the Rasa mines, is the red carbonate (Smithsonite) with more or less blende and galena, according to the points attacked. What renders this mine interesting is its apparent connection with the last fault to the south indicated in the map, and which apparently runs through the valley of Toporias. Cross courses are also met with here and at the Rasa; but their direction is so extremely irregular that no precise definition of them could be given. At the Rasa, as in the south part of the Dolores mine, the works continue principally in the direction of the bedding. Such is indeed a characteristic of all the mines in the dolomite, even where the general form of a lode is fully developed. At the Rasa three levels of ore have thus been discovered, although the dolomite has not in any instance been yet cut through.

§. 5. *Description of the Mines of Reocin and Mercadal.*

The beds of dolomite of the Rasa mines may be followed towards the S.E. until they lose themselves in the neighbourhood of the Saya river. The observations made hitherto tend to prove that they reappear at Reocin and Mercadal where they are characterised by the presence of masses of red calamine, slightly intermixed with galena and blende, and with great abundance of oxide of iron. The mines of Reocin and Mercadal are situated in two parallel valleys perpendicular to the course of the river Besaya, the former at about $1^{km.}$, the latter at about $2^{km.}5$, from the point of junction of that river with the Saya, near Torre la Vega. The stratification of the rocks is very distinct, the beds at Reocin dipping towards the north at an angle of between 20° to 25°, whilst at Mercadal, more to the south, the dip increases to about 30°. The river from Puente San Miguel flows in a valley bounded on both sides by horizontally bedded sandstone, very loose in texture and highly charged with oxide of iron and some oxide of manganese. Here and there the eroding action of the river has uncovered portions of limestone and dolomite beds—the three kinds of rocks rising up gradually towards Reocin, and thus forming the northern boundary of the valley in which lies the deposit of ore. Its length from east to west would be about $2^{km.}$, the breadth from north to south being about $700^{m.}$ to $800^{m.}$ The dolomite, which crops out along the northern side of the valley from under the sandstone and limestone rocks already mentioned, rises in elevation towards the west, where, in close contact with the limestone of the south side, it shuts in completely the valley. The space between the dolomite on the north and the limestone rock on the south is almost entirely covered by an immense lake-like deposit of red ochreous earth, highly charged with oxide of iron, and in certain points with nodules and small fragments of Smithsonite, to such an extent as to have rendered it a very profitable operation to wash them. The great mass of the ore has been found near the eastern extremity, and penetrating the dolomite. The deposit here assumes the form of a *filon couche*, or "flat vein", more characteristically than anywhere else in the province, an entire bed of dolomite seeming apparently to have been replaced by the carbonate of zinc, as in the case of the "Emilia" already noticed. The substitution of carbonate of zinc for the rock, and the filling up of joints so frequent and so wide in the beds of dolomite, has been so extensive as to have rendered mining operations often dangerous, on account of the necessity of removing the ore from the planes of bedding and jointing. The red ore has been followed up by shafts and adit levels along the northern side from east to west, in which direction it thins out. The accompanying iron ore is, however, found here as abundantly as elsewhere in the valley.

Taking into consideration the very large production of calamine ores (about 80,000 tons mostly of calcined ore up to the year 1861), the small quantity of blende and galena found is remarkable, as is also the very great abundance of oxide of iron in the accompanying earths.

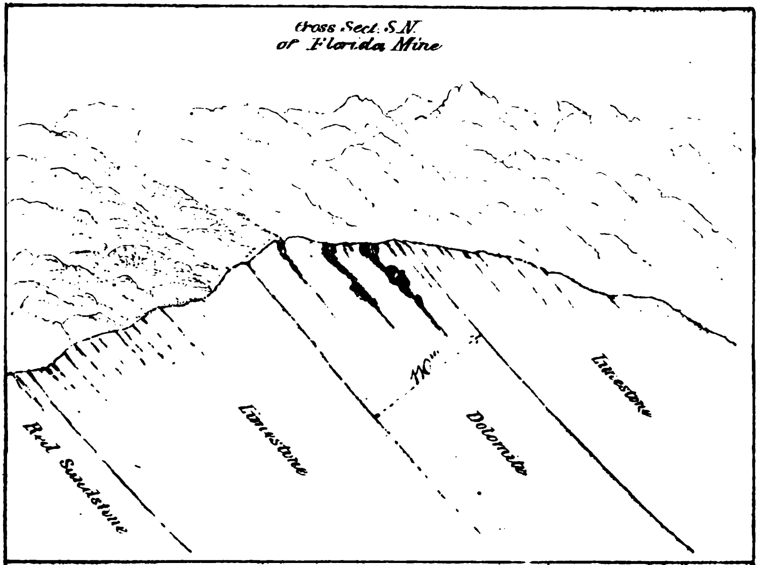
At the base of the dolomite are found beds of a dull, black coloured limestone, seemingly identical with that from which a very fine cement is made at the valley of Udias, and which on that account might serve as a point of connection between these mines and those of Udias. In the lowest of those beds, which crop out along the south side of the valley, and which, tilted up towards the south, form a ridge of hills constituting the northern boundary of the valley of Mercadal, are found deposits of white calamine, having many of the characteristics of the similar ores from Udias, except that they are generally more earthy, and exhibit but rarely the stalactitic structure which is so remarkably developed in the ores from the mines of the last mentioned group. Massive blocks of limestone, seemingly detached from their beds by the combined action of water and weather, occur here, and imbedded in them are found rounded nodules of zinc ore, which remind us of the septaria in the clay beds, the nodules and balls of clay iron in coal measure strata, and the concretionary oxide of iron found frequently in many limestones.

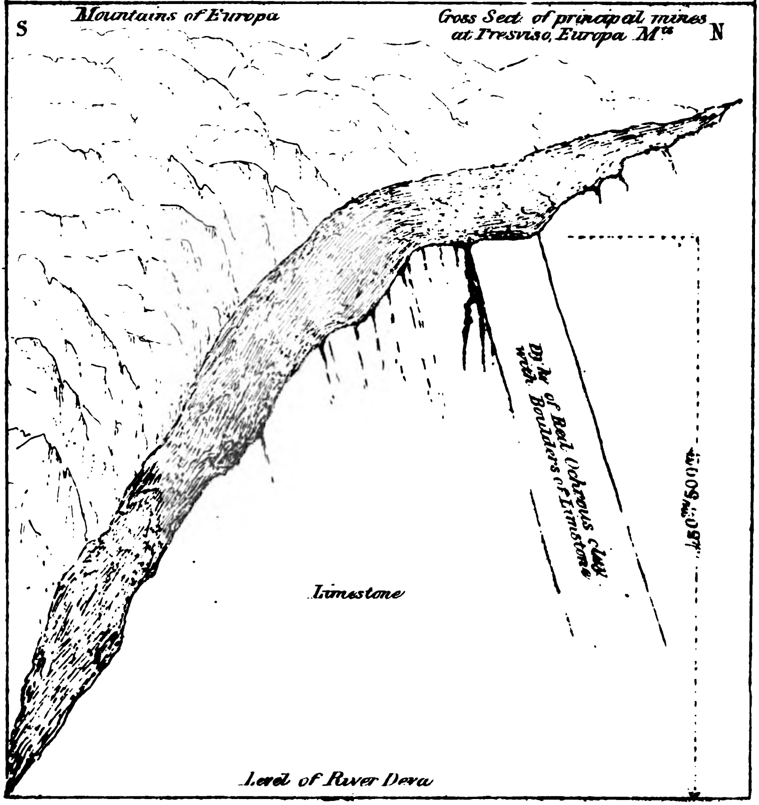
As has been already mentioned, the ridge of limestone rocks which forms the southern boundary of the Reocin valley, separates it from that of Mercadal, the distance between them being about 1,500$^{m.}$ The dolomite, which crops out here on the north side, is very limited in extent, when compared with that of Reocin, the thickness being much less, and the mineralized portion not extending over more than 800$^{m.}$ east and west. The character of the ore is very different, presenting at the point where most abundant a strange mixture of blende, galena, calamine, iron pyrites, and oxides of iron, the whole being of inferior value on account of the expense of dressing it. To the east of the central point (Maximina mine) occur pockets of red ore, filling up joints in the beds of dolomite, and forming local deposits in the bottom of the little valley, underneath a thick bed of red ochreous earth, like that found at Reocin. Here, again, white calamine presents itself in the limestone beds, which rise up on the south side from under the overlying dolomite. The occurrence of a bed of slate-clay between the two establishes a certain similarity with those of the north side of Udias.

§. 6. *Description of the Florida Mines. Plate* 15.

Those mines are situated at about six miles to the S.E. of San Vicente de la Barquera, and have taken their name from the mountain on the summit of which they are found. The

PLATE No. 15





Bellew's Lithog. Dublin.

ridge extends in one continuous line for about one mile from E. to W., along the whole of which crops out a thick bed of dolomite, in which calamine has been found (see section II., Pl. 2, and the cross section from south to north of Florida mine, Pl. 15). This bed dips towards the north, at an angle of 45° to 40°, the latter being general. Its thickness varies between 110$^{m.}$ to 120$^{m.}$ along the mineralized line. The dolomite may be traced much farther to the east and to the west; but, as the ground is very irregular in both those directions, it is not easy to indicate precisely the connection. Nevertheless, there are many reasons for presuming that this bed corresponds with that of Mercadal and Reocin, although the thickness is apparently greater. This hypothesis, however, is much strengthened by the characteristics of the ores. On comparing the conditions under which they are found with those already described as existing at the Venta, it may at once be seen that there exists no anticlinal here, nor are any characteristic faults or elements of a lode to be traced. The ore is principally met with in the intervals between the beds of dolomite, and in the works which have been opened up, the thickness of the ore deposits is generally greatest near the surface, thinning out in depth. Although ore is found at several points along the line of outcrop—a fact which establishes a connection between the main deposits, distant from each other about 1,200$^{m.}$ —yet, on the whole, those deposits, of which three principal ones have been worked, are very circumscribed.

In the mine known as "Clara", situated to the extreme east of the line, there exists a system of cross joints, having the character of lodes, running N.W. and S.E., as at the Venta, but much less developed than at the latter.

The ores of the Florida are characterized by: 1. a greater abundance of galena, which occurs in a more isolated way than at the Venta, and is also accompanied in many specimens by crystals of carbonate of lead; 2. a smaller proportion of blende, and that more transparent, that is, less ferruginous, and generally reniform in structure; 3. a greater abundance of sulphate of barytes, which presents itself along the whole mineralized line, but principally near the western extremity, in the outcrops of the Isidore mine, where it has all the well-known characters of that mineral; 4. more frequent occurrence of oxide of iron and pyrites, into which ore the veins of calamine often pass as they thin out in depth. The works have not as yet attained a greater depth than from 30$^{m.}$ to 35$^{m.}$, so that no opinion can be formed as to their extension in depth, however apparently well founded may be the hypothesis which would lead us to infer their continuity in this direction.

These mines have been looked upon as an excellent exemplification of a *filon couche*, or "flat vein". The fact, however, of the existence of cross courses is interesting, and establishes a point of connection between the Florida mines and that of the Venta, where such "filons couches" also exist, as has been already noticed, but where they are, however, of secondary importance. Up to the year 1860 the produce of those mines amounted to about 7,000 tons, of which 100 tons at least were pure galena. As regards produce, they are consequently inferior to the other principal mines of the province, although on account of their greater regularity of structure and greater abundance of galena, they have inspired greater confidence in their mineral wealth.

§. 7. *Description of the Mines of Puente Arce and Santander.*

The dolomite of Reocin and Mercadal, which disappears under the overlying beds in the neighbourhood of the river Saya, is completely covered over by the immense deposit of sandy clay, full of quartz boulders, upon which Torre la Vega is built, and portions of the lower cretaceous formation, the horizontal beds of which form low promontories all along the river down to its mouth near Suansez. Farther on to the east, it again reappears near a point called Puente Arce, with its accompanying beds of limestone and sandstone. The stratification is here still nearly horizontal, the planes and joints being easily recognizable. They contain mineral matter, in which, while traces of calamine and blende occur, iron ores may be considered as exclusively predominating, the same ochreous earth filling up the hollows, clefts, and depressions of the ground, as was described in speaking of the valley of Ciguenza. This circumstance forms thus a connecting link between the mines already described and those situated about Santander, where the dolomite reappears with its accompanying beds, and in which crop out galeniferous red calamine and blende of an unproductive nature, and immense deposits of oxide of iron connected with beds of pyrites, of which some are still left extensive enough to justify mining operations. It is remarkable that the reniform structure predominates in these pyrites; the oxide has not, however, this texture, but is, on the other hand, highly scoriaceous or tufaceous, and in this respect very similar to certain red calamine ores. The ore is of excellent quality, as may be judged from the fact that it was formerly smelted with wood charcoal from the neighbouring mountains, and used by the government at a cannon foundry, which Charles the Third established at the Cabada. The abundance is such that the country people could gather the ore from the surface of the neighbouring mountains, Peña Cabarga, etc., and deliver it at the point of embarkation for about four and six pence to five shillings per ton. Those deposits of hæmatite extend all round the bay of Santander towards the west and south in solid masses, but generally sufficiently loose in texture to allow of their being worked at a very low cost, the expenses being, however, greater in those places where the massive nature of the ore renders mining to a certain extent necessary, and where the superficial deposit has already been worked away; nevertheless, even under those conditions it has been worked to a considerable extent at about ten shillings per ton, the expenses of charging aboard ship being included in this sum.

§. 8. *Description of the Mines of the Dobra range and Viesgo, of Merodio, and Tresviso. Plate* 15.

The mines already described lie between the sea coast and the Dobra chain, which runs from E. to W., passing Puente Viesgo, Las Caldas, near Cabazon de la Sal, and finally merging into the mass of mountains which line the eastern side of the river Deva. Although no mines extensively productive occur along this line, nevertheless, there are found numerous indications of ores so peculiar in their nature, and so interesting when contrasted with those of the other groups, that they deserve at least a brief notice.

The main axis of the chain consists of limestone in which the bedding is not easily recognizable, partly on account of the metamorphic action which it seems to have undergone at the parts exposed. It is very much jointed, somewhat like granite, although the joints are more numerous and complex. No fossils or indications of them have been found up to this time, either in this limestone or in the highly inclined beds of sandstone which rest upon it at both sides of the chain, as is shown in section IV., Pl. 3. As this chain is traversed perpendicularly by three of the principal rivers of the province, the valleys of intersection present very favourable conditions for determining the relations of those rocks. At two of those points, Puente Viesgo and Las Caldas, hot carbonic acid springs exist, the temperature of that at Viesgo being 35° C., and that of Las Caldas 37°·5 C., while the Hermida springs, of which mention shall be made hereafter, situated in the valley of the Deva, have a temperature of 52°·5 to 56°·25 C. All along the chain traces of galena and associated carbonate of lead, blende, calamine, copper pyrites, and carbonate of copper, occur mostly in the principal mass of limestone. At certain points those mineral indications attain sufficient importance to be worked as mines, as at Puente Viesgo, the point known as Sitio de la Trecha, immediately overlooking the village of Sapenilla, etc. At other points small lodes or pipe veins, which are met with along the chain, have long been worked for galena by the peasantry. Between Las Caldas and Puente Viesgo, the outcroppings are almost continuous along the axis of the mountains, presenting themselves generally nearer to the northern line of junction of the sandstone and limestone. The ores are usually accompanied by calc spar, and consist of the mixture already described, the galena and blende, however, predominating. Near Las Caldas, two lodes have been met with, of which one has been worked for blende and galena. The other, situated at the Sitio de la Trecha, had the character of a regular lode or vein, about $0^{\text{m}}\cdot70$ thick, dipping to the W. 15° S. at an angle of 55°, the strike being N. 15° W., when the workings had attained a depth of $6^{\text{m}\cdot}$ and the outcrop had been uncovered to the extent of $35^{\text{m}\cdot}$ The walls were lined with a thin layer of a greenish plastic clay; the mineralized portion was principally composed of two parallel bands or ribs, the under one being calamine, the upper, or that near the roof or hanging wall, and about one-fourth of the total thickness was blende, intermixed with a little carbonate of lead, galena, and cinnabar. Situated at a point of difficult access, and not presenting the qualities required in a lode to render its working profitable, purity, mass, and continuity, this lode was not considered worthy of further investigation.

Going eastwards from this mine along the axis of the chain, nearly vertical, thin veins of copper ore, imbedded in calc spar, occur in the mass of the limestone, but are only traceable for a few metres. At other points towards the northern junction with the sandstone, pockets containing galena and Smithsonite in small quantities have been found, the accompanying clay being here highly ochreous. But up to Viesgo no considerable mass of ore has as yet been anywhere met with.

Here the chain is traversed by one of the principal rivers of the province, and presents a highly picturesque mountain pass, the limestone rocks standing out boldly on the western side, while on the eastern, in front of the village, those same rocks seem to have been considerably eroded, and have a much less precipitous declivity, the red sandstone immediately in contact with the limestone running out on the north side, towards the river, forming thus a spur, which closes in the valley on that side of the village.

Near the summit of the eastern declivity, in front of the village, and almost in contact with the red sandstone, are found irregular veins or pipes of carbonate of lead and galena, blende and Smithsonite being the exception. The irregularity is here very great, the fragments of limestone, which are highly saccharoidal in texture, seem to have been brought into their actual position by some violent disturbing action; veins of rosy calc spar are very frequent; and the clay which lines the cavities has a pinkish flesh colour of variable intensity. This earth has imbedded in it great numbers of doubly terminated prisms of clouded quartz; there are likewise found in it pieces of calc spar, dolomite, oxide of manganese full of small quartz crystals, and white or rosy amorphous carbonate of lead, for which the greater part has been washed. Masses of pure galena, weighing from $10^{\text{kgm.}}$ to $50^{\text{kgm.}}$, always covered externally with a thin coating of carbonate of lead, have also been taken out; the latter ore forming, however, the principal mass of ore hitherto extracted. Numerous thin veins of a green, soft talcose clay run through the limestone here; when exposed to the air for a short period, it entirely decomposes into a highly plastic clay of variable colour, being sometimes of a pale cream colour, sometimes of a rosy or reddish colour, but always different from that of the undecomposed mass. The pinkish flesh coloured clay, which forms the matrix of the ores just described, is obviously connected with these veins of talcose clay.

At the foot of the declivity above mentioned, near the bank of the river, and close to the junction of the red sandstone with the limestone, are the hot springs of Viesgo, which enjoy a considerable reputation in the province for their medicinal properties. A most remarkable mass of indurated red ochreous clay, having the appearance of a dyke, stands out from the surface of the ground near the springs, whose action it seems to have undergone.

At about $2500^{\text{m.}}$ to the E.S.E. of this point, and near the junction of the red sandstone, on the northern side of the chain, another mine occurs, presenting the same features in respect of ore, and containing carbonate of lead, as at Viesgo, except that here galena predominated. In the intermediate space indications of ores have been met with, forming as it were so many connecting links, while still farther to the east, certain other outcroppings seem to prove a considerable extension of mineralized ground in this chain.

To the west of Las Caldas, other mineralized points have been noticed, and in some cases even worked by potters for galena. Another remarkable fact to be noticed, is the recurrence of the peculiar quartz crystals of Viesgo, imbedded in a portion of the limestone rocks which line the eastern bank of the river Deva, at a point called the Peña Mala, and also in the massive Smithsonite from the mines of Merodio. Near the point in question, a copious fountain pours out from the side of the path, seemingly one of many that formerly existed in the highly fissured rock.

The hot springs of the Hermida, of which mention has already been made, occur about five miles from this point, further up the course of the river Deva, on the eastern bank. The valley is here narrow, being only the breadth of the river and of the road which runs along the western bank, about 80$^{m.}$ altogether; on both sides the limestone rocks, through which the river has cut its way, rise up almost precipitously to a considerable height. The tortuous road leading to the mines of the mountains of Europa, commences here, and, by continual windings, attains the first plateau, situated at 800^{m}. to 900^{m}. above the level of the river. The springs issue from clefts in the rock at the level of the water, and are very abundant, the temperature, as before stated, being 52° to 56° C. On examining the map, it may be remarked, that their position corresponds very nearly with the intersection of the Dobra chain with the river, and that consequently these springs are very probably intimately connected with those already described as existing in that chain. Their position is rendered still more interesting by the circumstance that the valley of the Hermida is traversed diagonally by a nearly vertical dyke of red ochreous indurated clay, striking N. 23° W., S. 23° E., dipping slightly to the N., and whose greatest breadth may be estimated at about 35$^{m.}$ to 40$^{m.}$ The springs are situated at the point of contact of this dyke, where it traverses the bed of the river. From this point it rises on both sides of the valley, following the conformation of the limestone rock, and attaining its greatest elevation towards to the north, on the summit of the promontory formed by the junction with the river Deva of the mountain torrent, which, fed by the ever-melting snows of the Peñas de Europa, flows at the foot of the precipitous mountain on which is situated Tresviso. At this point, named Osuña, rendered remarkable by the occurrence of outcroppings of white anhydrous carbonate of zinc and galena, it seems to be inflected towards the west, traverses the torrent, and apparently constitutes the mineralized ground of the Tresviso mines. Towards the south, the dyke, rising with the declivity of the limestone, is traceable for at least two miles beyond the Hermida, seeming to pass near the mountain village called Linares, and probably continuing on up to the elevated mountain pass known as the Puerto de Libeña, where a mine of red calamine, blende, and galena, has been worked in the limestone. Along this southern part, although not in the immediate vicinity of the dyke, outcroppings have also been observed, the Smithsonite being generally exactly similar to that of Merodio, with traces of copper, while the galena, where found, was associated with white quartz, as will be noticed in the description of Tresviso.

The most remote indication of Smithsonite towards the south presented itself under very peculiar circumstances. At this point, situated near the junction of the limestone with the overlying red sandstone, the dip of which was easily ascertained to be 45° to the east, on account of the regularity of the bedding, was found a large mass of fine greenish semi-translucent Smithsonite. It was firmly imbedded in a nearly vertical and yet open cleft of the rock, and was completely isolated, no apparent trace of any other ore being recognizable. The accuracy with which it fitted in the cleft, as well as the elevated and almost inaccessible position in which it was found, precludes the idea of its having been carried there. It is difficult to conjecture how it came there; but the simplest hypothesis would seem to be, that it was formed *in situ* by the action of a spring. We need not discuss this subject further here, as we shall have something to say upon the action of hot springs further on.

If, when standing on the summit of the Florida mountain, we look to the westward, the great limestone masses which form the Peñas de Europa stretch themselves out very distinctly before us; the bedding is well marked, and enables the eye to follow very clearly the contours of the successive ranges of hills, which seem to rise one above the other from the sea coast. In one of the lower ranges, and somewhat to the south of the continuation of the axis of the Florida, near the village of Merodio, an interesting group of mines was discovered. The limestone here is lithologically the same as that immediately to the south of the Florida mountain, and corresponds to that of the chain of the Dobra, as was already noticed in a previous part. The opinion that the ores in the two limestones are due to identical causes is greatly strengthened by the abundance of small doubly terminated quartz crystals, which are found sometimes isolated, and sometimes aggregated together so as to form a nearly white mass of loose texture, and which resembles in many respects those found at Puente Viesgo. The Smithsonite is found associated with those quartz crystals, the latter being sometimes found imbedded in considerable abundance in massive white Smithsonite, almost wholly free from silica, in what were usually considered to be true lodes in the limestone. In some cases the deposits are, however, irregular, and generally thin out in depth, a circumstance which, joined to the great difficulty of getting access to them, rendered the works undertaken unprofitable. The ores are, however, very interesting, and form a necessary link of connection between those already described and those found at Tresviso, in the valley of the Deva, and higher up among the Peñas de Europa.

However insignificant the deposits or indications of ore which we have been just noticing may be, they possess much interest when taken in connection with the mines of the Peñas de Europa, and those less productive, but equally interesting ones of Tresviso, where, as has been already mentioned, the mineralized dyke passes. The little village which gives its name to the mines is situated at the western extremity of a narrow plateau which overhangs the mountain torrent already alluded to as joining the Deva near this point. The access is really difficult, the escarpments of both sides of this wild valley being extremely steep. On the south side live oaks and beech trees clothe the almost perpendicular rock from near the brink of the torrent to the lofty peaks above, while on the northern side the less abundant vegetation seems to be continually menaced with destruction by the falling of detached blocks or fragments of rock from the heights. The great alternations of heat and cold to which this side is exposed has produced at certain points, where the declivity approaches 45°, such an accumulation of ever succeeding fragments of rock as to form large bands of loose shingle and boulders extending from near the summit of the mountain down to the very stream. It can easily be conceived that such a surface, where the displacement of a single pebble brings down hundreds of others rolling and bounding to the water's edge, offers no hold for roots, and renders the construction of a road almost impossible. A wild zig-zag and very difficult mountain path, hewn for the most part in the rock, and necessarily crossing two of those avalanches of stones, leads from the bank of the Deva to the village. The dyke already spoken of as traversing the bottom of the valley of the Hermida can be distinctly recognized here; and its association with ores at this point is quite distinct. Three different outcroppings had been worked between the village and the point where the dyke inflects itself before traversing the torrent. The first, situated a little to the west of the village, and near the northern junction of the dyke with the limestone, presented, when visited in an inclined shaft of $6^{m.}$ to $7^{m.}$ in depth, white Smithsonite imbedded in a white crystalline quartzose rock of precisely the same nature as that described as existing associated with galena near the village of Linares, on the east side of the valley of the Hermida, and strongly resembling the associated quartz of the Dobra chain. Traces of copper were here distinctly noticeable as round green spots, a circumstance which is explicable by the existence of a mine of gray copper in the neighbouring mountain. The shaft was sunk at the foot of a fine massive outcrop, departing from which indications of ore could be distinctly followed up along the surface to the next shaft. Here the indications of ore were more extensive and more important, and were all observable along the southern contact of the dyke with the limestone. The principal ore extracted here was galena, of which large lumps were found isolated in a mass of white Smithsonite. The latter ore was, however, the predominant one, and seemed to continue in depth; in many places it formed a thick exterior coating on the vertical surfaces of the limestone joints. The shaft itself was continued irregularly to a depth of about $35^{m.}$ following the joints or clefts of the limestone, which, at certain points, were quite open and free from any filling matter, thus presenting all the characteristics of pipe veins. The galena generally came out associated with quartz. From the appearance of the calamine in certain parts of this irregular shaft, little doubt could be entertained of its stalactitic, and consequently aqueous formation. The rarity of blende was remarkable; it however exists in the lode, being met with in the shaft most distant from the village to the east. This mine, known as the San Leonardo, had reached a depth of about $24^{m.}$, and presented on all sides intermingled white Smithsonite, lamellar transparent blende and galena, each of those ores standing out distinctly from the white limestone rock, and contrasting thus most markedly with the corresponding classes of ores found in the mines nearer the sea. The blende predominates here as regards mass, a circumstance which apparently is due to the rock not having so many fissures and vents as in the mine described above, through the agency of which the transformation into carbonate would have been facilitated. No quartz was noticed here, which leads to the supposition that in the other mines its presence was connected with the metamorphosis of the blende.

§. 9. *Description of the mines near Reynosa and in the valley of Potes, or those of El Soto and Pico Jano.*

The river Besaya, which traverses the Dobra chain at Las Caldas, opens a more easy approach to the main chain of the Cantabrian Pyrenees than any other river of the province. Along its banks runs the principal line of communication with the southern provinces, both the high road and the new railway of Isabella the Second following the windings of the valley as far as possible. Beyond Las Caldas the valley opens out for about two miles, though still encased by spurs of the main chain, which further on again close it in, forming thus one of the defiles or mountain passes, known here by the term *hoz*. The rocks here are entirely red sandstone, scarcely any limestone being met with along the river until near Reynosa. The main mass of the sandstone is red, although brown hues are to be met with. The rocks of both colours forming distinct thin beds of flagstone, at other times, as near Barcena, forming thick horizontal beds perfectly homogeneous, and remarkably well suited for building purposes, as is advantageously shown by its use in constructing several bridges of the railway. The high road, which generally follows the incline of the river, here a real torrent, is very picturesque, and affords ample opportunity for the study of the high precipitous banks. This is more particularly the case at the point known as the *Hoz*, where commences the defile that only ends at the plateau of Reynosa, between 800$^{m.}$ and 900$^{m.}$ above the sea. Not far from the entrance of the Hoz, traces of a copper lode, which at one period was even worked, may be noticed in the red sandstone which here overhangs the river. Further on, and at about six miles from Reynosa, the underlying limestone beds crop out by the side of the road, and form a talus of broken rock at the foot of the overhanging cliff, somewhat similar, although on a much smaller scale, to those of Tresviso, which affords a very convenient "road metal". The limestone is here, however, blacker than at Tresviso. From this point it may be traced on to Reynosa, always having the same physical character, and near the town is associated with a very extensive and apparently irregular deposit of mottled violet and gray clay, in which are imbedded masses of gypsum, generally saccharoidal in structure, and frequently rose coloured.

The under part of this limestone extends itself over certain parts of the undulating ground which lies to the N.W., between Reynosa and the southern crest of the mountain chain, being more or less irregularly dolomitised. Indications are met with here of calamine, blende, galena, and hæmatite, much resembling the ores found in similar rocks near the sea coast. They do not seem to be distinguished by any peculiarity from the red ores already described; the outcrops, when visited, appeared very insignificant. However, on proceeding farther on to the west, past the source of the Ebro, and towards the summit of the crest, a very interesting mine of copper is met with at a point called "El Soto".

Of such copper mines but two of known importance occur in the province, the one just noticed, and another situated on a peak called Pico Jano, to the south of Potes, apparently in the continuation of the same chain of mountains. The lodes "del Soto" occur in a sandstone which immediately underlies the last described limestone beds, which dip here to the south at an angle of 20°, and crown the summit of the chain. The first beds of this underlying sandstone, with thin beds of clay intercalated, have a similar dip, while the lower beds, which crop out continuously down the side of the hill, exhibit a decreasing dip until the beds become nearly horizontal, and in these have been found the copper lodes. The sandstone itself differs lithologically from that already described as red sandstone, being more of a grayish hue, harder and more difficult to work. Its texture would correspond more or less to that of millstone grit, or to that of certain beds of sandstone belonging to the coal measures, as they occur in the Asturian basin.

In this rock have been discovered five lodes running nearly east and west, that is to say, parallel to the general direction of the chain of the Cantabrian Pyrenees. Their dip, which is towards the north, is about 80°. The distance between the extreme lodes is about $80^{m.}$ to $100^{m.}$, and their general thickness varies from $0^{m}{\cdot}50$ to $0^{m}{\cdot}70$. Being worked by an adit level, at the most $150^{m.}$ long, driven in a northerly direction, no great depth from the surface was attained; the ore which came out from the different levels was, however, perfectly well characterized as copper pyrites with a quartz gangue. Several of the lodes when visited yielded iron pyrites, into which the rib of ore seemed to thin out completely in some cases—that is, the sulphide of copper diminished as depth was attained. The lodes had not been traced very far superficially, so that when visited no opinion could be formed as to their continuity in direction. No calamine or blende appears to have been met with. This circumstance is interesting when we take into account the close proximity of galena, blende, and calamine, indications of which have been already stated to occur in the dolomitic rocks situated between Reynosa and the foot of the mountain range.

The copper mine of Pico Jano, already referred to, is situated on the summit of one of the mountain peaks which surround Potes. The approach to this town is by the valley of the Deva, which, encased on both sides, as already described when speaking of the Hermida springs, by the lofty overhanging mountains, continues to present nearly the same highly picturesque and interesting defile for about six miles beyond the Hermida. A bend in the river, or rather torrent, here reveals a change, not only in the exterior character of the country, but also in its physical constitution and natural products. At this point crop out the beds of slate clay and sandstone, which seem to underlie the great mass of limestone constituting the Peñas de Europa. The erosive action of the torrent was naturally greater in those beds than in the limestone; the result of which has been the formation of a valley running nearly E. and W., entirely shut in on all sides by high mountains, and having but one practicable outlet to the surrounding country, that by the valley of the Deva. On the other hand, the beds of slate clay have furnished a soil of comparatively easy cultivation, even at points apparently inaccessible, and seeming peculiarly well adapted for the production of grain crops, and the culture of the vine, which has almost disappeared from the rest of the province. The protection afforded by the surrounding mountain chains seems to have an equally favourable influence on the climate, the variations of temperature being less violent than in the more level country, while the solar heat, so necessary for the vine, here acquires additional force and concentration. No more marked example of the intimate connection between local physical conditions and the characteristics of the population could perhaps be offered, than that of the valley of Potes.

To the N.W. of the valley stands out boldly the lofty, and here precipitous, chain of the Peñas de Europa, in the deep chasms of which patches of snow may be observed to remain nearly the whole year, although, from their southern aspect, exposed to the heat of a Spanish sun, which the white surface of the enclosing limestone rocks render still more active. Nearly opposite them, at about five or six miles to the west of Potes, stands the Pico Jano, rising as it were out of the Deva, which flows at its base in a nearly E. and W. direction, and which has its source a couple of miles to the west, higher up in the valley. The mountain path by which the ascent from Potes to the mine is made, passes continuously over beds of slate clay and sandstone up to the highest point, where are found the indications of copper. The mountain juts out in the valley, presenting a narrow but comparatively level summit, whose length runs N. and S. The declivity towards the valley is formed by thick beds of quartz conglomerate, from under which crop out apparently conformably beds of hard gray sandstone, sometimes passing to blackish gray, dipping to the north at an angle of 50°.

Four out of five lodes have been found to converge towards one central point, situated at the summit, near its northern extremity. The first discoverers of the mine sank a shaft at the point of intersection, but only to a very inconsiderable depth. It yielded, however, variegated copper pyrites, in a quartz gangue, so abundantly as to encourage the driving of an adit level 186$^{m.}$ long on the northern side of the mountain, so as to cut the supposed lodes at about 200$^{m.}$ below the surface. This was incomplete when last the works were visited, but had already furnished some indications of a metallic vein.

The veins of quartz seem to traverse the valleys on either side of the Pico Jano, and outcroppings of ore have been found in the neighbourhood, but it is not positively known whether they belong to this particular set of lodes or not. The similarity in several points between the characteristics of the Soto mine and those observed here, is extremely interesting, and hence a brief description of the Pico Jano mines was necessary to complete our sketch of the geognostical features of the mineralized portions of the province.

IV. MINERALOGICAL STRUCTURE AND CHEMICAL COMPOSITION OF THE ORES, WITH SOME REMARKS UPON THEIR MODE OF PRODUCTION.

Having described in the foregoing parts the general geological features of the province, and the special geognostical conditions under which the ores occur, we propose in the following part to describe their mineralogical characters and chemical composition. We shall divide it into four sections, of which the first will be devoted to a detailed description of the structure of the ores of each set of mines; the second, to an account of certain peculiar structures, of which we had occasion to observe the formation; the third, to a statement of the results of the analyses of several ores; and the fourth, to the conclusions which may be deduced from a study of the structure and composition of the ores, taken in conjunction with their mode of occurrence, regarding their mode of formation and probable relative geological age.

§. 1. *Mineralogical description of the ores.*

Mines of Comillas.—The ores of the mines of Comillas, as we have described in the preceding part, consist of blende, Smithsonite, and galena. The blende offers some interesting peculiarities: where it occurs in mass, it is highly crystalline and of a brown colour; this mass appears to have been subjected to disturbing forces which cracked it in various directions, after which it was resoldered by carbonate of zinc. Wherever cavities have been formed in the principal deposit, detached pieces of the ore are found partially filling them; those fragments are angular and are connected together by carbonate of zinc. It does not form a compact breccia, but a clinkery cellular mass. The surfaces of the blende are generally reniform, and sometimes perfectly hemispherical masses occur. The section of the latter shows that each hemisphere consists of concentric shells of blende, with generally a very small hole in the centre, so that they seem to be the ends of stalactites. The reniform and globular masses are frequently coated by a concentric layer of sulphate of barytes, the external surface showing crystals of that mineral, which are pseudomorphites of calcite or bitter spar. Sometimes the coating of sulphate of baryta is quite friable and crumbles into powder, consisting of small prismatic crystals. Others of the reniform and globular masses have their surface covered with a multitude of small crystals of blende, having exactly the appearance of having been precipitated from a solution upon a projecting object. Sometimes these small crystals are covered over by a thin film of crystalline carbonate, which acts as a cementing material to the fragmentary mass, and which frequently forms thin partitions, not thicker than paper, running through the spaces left between the cemented angular fragments. Occasionally these films form small shallow cups or trays, containing small crystals of blende, similar to those coating the globular masses; the tray often contains only a few crystals of blende, resting upon the points of carbonate of zinc, forming the almost invisible asperities upon the surface of the films; at other times it is quite full. In either case one of them looks like a capsule in which crystals have crystallized out of a solution. In one instance, minute cubes of galena, some resting in the interspaces of crystals, and others on the points of the blende crystals, were found. In one characteristic hemispherical concentrically formed knob, small cubes of galena were disseminated through it. This specimen had all the appearance of a stalactite. The concentric shells are indicated usually by an extremely thin line of a light brown colour, which examination with a lens showed to be slightly ferruginous earthy carbonate. In one case the line had become a well marked brown ring $0^{m}\cdot0015$ thick, composed of intermixed brown carbonate and blende. It seems as if it had been deposited as carbonate, and was gradually converted into blende. The small crystals found in the cups are apparently twins of tetrahedrons, the facets being extremely sharp and the cleavage easy.

The massive blende, the small crystals in the trays, and those coating the surface of the massive blende, are found decomposed. When the latter two decompose, they leave an orange ochreous powder, through which the decomposing blende is seen by means of a lens coming through in points, and exhibiting a curious caries of the surface and edges. Mammillated, globular, and reniform masses are found converted in whole or in part into carbonate; sometimes a coating is formed on the surface of a mamma exhibiting the imprints of the crystals underneath; in others the change of blende into carbonate has proceeded a considerable way in; and in others again all trace of blende has disappeared, and the mammilated mass is then composed of an agglomerate of fine crystals, which are disposed more or less, especially in the mammæ, in a radiated form like the original blende. Masses of this kind are quite porous, like an extremely fine sponge, proving that a considerable quantity of the original mineral had been carried away. Even the massive blende appears to have a globular structure, by the way in which it decomposes concentrically into earthy ferruginous Smithsonite. One specimen of this kind shows the conversion of blende into earthy carbonate in a most beautiful manner; it is a segment of what must have been a large mamma or stalactitic knob; at the point which represents what would have been the centre of the mass when complete, it is composed of friable hydrated peroxide of iron, containing traces of basic sulphate of iron, which shows that it is the result of the decomposition of a nodule of pyrites. Around this is found compact unaltered brown blende, very transparent in small fragments, but becoming duller towards the outer margin; a number of fine concentric rings of pale brown carbonate may be seen on the planes of section, as if the alteration took place along the concentric surfaces of shells of the blende. On examining the dull part of the blende with a lens, the dulness is found to arise from a mixture of blende and carbonate, the former oxidizing apparently along the cleavage planes. Outside all is a concentric shell of earthy light brown Smithsonite, which is quite friable on the outside, but a little harder inwards.

The Smithsonite when massive is saccharoidal, and not unlike, at first sight, many specimens of fine grained crystalline reddish dolomite; the greater part of it is, however, exceedingly cellular, or even clinkery. The cells are sometimes perfect druses, coated with small barrel-shaped crystals of carbonate of zinc;[12] in others, they are covered with a characteristic fine orange ochre, of which we shall have something to say hereafter; while in others again, a fine black spongy tissue of ferruginous oxide of manganese is found partially filling up small irregular cavities. This black matter is sometimes found filling up small cubical or square prismatical hollows, the angles of which are sharp, and are apparently the spaces left by crystals of galena; such crystals are indeed still found disseminated through the mass of red calamine. The black matter appears like a fine spongy net-work, completely filling up the hollows, and which, when examined with a powerful lens, is found to consist of a vascular tissue composed of minute tubes of oxide of manganese, which are perpendicular to the bottoms of the hollows, and consequently parallel to one of the planes of cleavage of the galena.

Some of the druses (many of which are often a foot or more in diameter) are coated with the characteristic barrel-shaped crystals, but of an orange or yellowish brown colour, so as to look like eisenkiesel; the crystals evidently contained some of the ochre disseminated through them, which is found as an efflorescence upon others. Sometimes the crystals have a peculiar black colour, and when examined with a powerful lens, appear cariated in a curious way, the black matter which was found to be oxide of manganese being deposited in the caries of each crystal. This curious phenomenon is obviously connected with the tubes of manganese, filling the moulds of the galena crystals described above.

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[12] None of the crystals in our possession are of sufficient size or perfection to enable us to obtain satisfactory measurements of the angles. We have hence given no crystallographic details in the present paper.

Small crystals of white transparent and smoked carbonate of lead are likewise found in the geodes of the carbonate of zinc. They never form a complete coating, but are often numerously sprinkled over the surface or lining fissures and small depressions in the surface of the geode. On the water-worn surface of one specimen of Smithsonite containing prisms of carbonate of lead, $5^{mm.}$ long, some being attached to the surface, and others imbedded in the mass, are numerous points which look like the rhombohedral terminations of hexagonal prisms, or rhombic dodecahedrons. They have the lustre of blende, and are evidently undergoing decomposition, the black matter being deposited as in the other cases.

Some of the red Smithsonite is exteriorly somewhat friable, the inside being hard and filled with disseminated transparent particles of blende; where the latter decay out, the mass becomes very finely cellular on the surface. These masses look like a conglomerate of blende and Smithsonite, such as would be produced by the crushing together of a mass of undecomposed blende and Smithsonite derived from the oxidation of blende, and the subsequent cementation and alteration of the crushed mass by the passage of water through it, holding carbonate of zinc in solution.

In some of the geodes of the massive calamine, white translucent opalescent, faint blueish white pear-shaped drops, and flat small mammæ coat the surface. Similar forms are found at Merodio; and as their formation affords an explanation of the mammillated, reniform, and botryoidal structure of minerals, we shall devote a separate section to the special study of those and analogous structures. Sometimes the surface of the blende, and especially the cups full of blende crystals, are dotted with very small warts of white zinc bloom, or zinc blüthe.

In pockets outside the principal lode silicate of zinc is found. This ore, which occurs in thin flag-like plates, is exceedingly compact, of a brownish red colour. The fracture across those plates is somewhat earthy, and not unlike that of fine-grained dolomite. On the north side of the principal lode, hard crystalline stalactites of carbonate of zinc, containing more or less silicate of zinc, were found.

Mines of Ciguenza and Oreña.—(*a.*) *Emilia Mine.*—The blende found at the Emilia is very similar to that of the Florida, which will be described further on; it occurs in a vein lined by very thin plates of barytes, and has a structure exactly like the radiated blendes of the Venta, only that here the crystals appear to be arranged as if at right angles to the walls of the lode. Sometimes the blende and dolomite pass into each other so completely that it is difficult to determine their limits; the fine joints of the former are filled up by barytes.

The joints of the dolomite are coated with drusy crystals of calc spar, chiefly the variety known as "nail heads", and with small rhombohedrons of bitter spar. The Smithsonite is red, dense, and highly charged with galena, but contains no carbonate of lead, and in certain parts of the lode passes into perfectly dolomitic carbonate. Some of the latter is found coated over with pseudomorphic crystals of sulphate of barytes after bitter spar, which are in turn coated with a rust-like coating of hydrated peroxide of iron. Beautiful opalescent lachrymæ of carbonate of zinc occur upon some specimens; others are coated with a complete envelope of mammillated white semi-translucent carbonate of zinc.

(*b.*) *Vicenta Mine.*—In the nearly vertical joints of the dolomite, a hard, clinkery ferruginous calamine forms a kind of lode in ochreous clay; in depth this becomes dense red dolomitic ore, full of druses wherever it happens to be thick enough; in some thin veins the carbonate of zinc passes into hæmatite. The druses are entirely coated with crystals of Smithsonite, and, in some cases, with warts of zinc bloom, and the former in turn by a fine layer of silicate. Botryoidal lachrymæ also occur in the druses associated with zinc bloom.

Mines of Reocin.—Three kinds of ore occur here: 1. Massive red carbonate, found in a bed replacing, as it were, dolomite; 2. Small nodules mixed up with ochreous clay in the bottom of the valley; 3. White calamine, found in the underlying limestone, but in immediate contact with the dolomite. The massive red ore contains a considerable quantity of water; and stalactitic masses of it occur in the mine, which have exactly the structure of compact calc sinter. In the marly limestone, immediately underlying the dolomite, grayish white concretions of carbonate of zinc are found, the results of an analysis of one of which will be given at page 104. Some peculiar fossil-like concretions found in the same bed have the same composition.

Florida Mine.—Galena, blende, and pyrites are here associated, and are all three simultaneously decomposed, giving carbonate of lead, which is found in large transparent crystals, calamine, traces of hydrocarbonate of zinc, and brown hæmatite, derived from the pyrites; thus affording a beautiful example of the passage of sulphides into carbonates. Earthy phosphate of lead also occurs like a kind of mould upon some specimens.

Galena occurs in a very characteristic form, consisting of globular masses, which consist of concentric shells exactly like the blende of Stas. Lucita and Felix; some of the specimens appear to have been distinctly formed around a nucleus, which in one case was blende. The cleavage planes of the galena pass through the shells, and are so distinct in the outer one, that it looks as if it was foliated. The solid of cleavage is not, however, a cube, but is distinctly rhombic, as if it had been subjected to tension during deposition. One specimen of this galena shows two tangent spheres or kidneys, the planes of contact being beautifully shown by the oblique intersection of the cleavage planes of each sphere. The central nucleus of blende in those spheres gradually passes almost insensibly into the galena, so that it is impossible to mark a line of junction; the outer layers appear, however, to be perfectly pure galena free from silver or zinc.

The blende of Florida is also spheroidal, and exhibits concentric layers, some of the decomposing masses still containing undecomposed blende being even pisolithic. No specimen of true globular blende has, however, been found; the masses are rather stalactitic, mammillated, and sometimes almost completely reniform.

Ore occurs in fissures occupying planes of bedding, forming what may be called "flat veins"; in the pockets of those veins a curious silicate of zinc occurs, consisting of irregular masses of a globular structure, sometimes forming beautiful botryoidal bunches. The globules were nearly uniform in size, the largest being about one centimetre in diameter, and consisted of radiating prisms of a brownish yellow colour. A fuller description and the results of its analysis are given at p. 116. In the pockets of the same class of veins near the surface a clinkery reddish brown silicate of zinc occurs, which appears to have a somewhat analogous composition to the globular mineral just mentioned. A great deal of oxide of iron is associated with the zinc ores of La Florida, and in some cases the zinc seems to disappear, and to be replaced by iron as at Oreña. This oxide of iron is derived in part from the decomposition of pyrites, which is found here, as we have above mentioned; a part of the oxide of iron is, however, in combination with silica, formed perhaps by the action of a solution of disilicate of zinc upon sulphate of protoxide of iron.

The carbonate of zinc of Florida is massive, of a reddish colour, and very dolomitic looking, and subcrystalline. A net-work of colourless crystalline lines runs through a good deal of it. On dissolving a piece of it in chlorhydric acid, a honeycomb of crystallized sulphate of barytes was left behind, almost identical with the similar crystalline nets which are formed by the springs of Bagnères de Luchon, and which even exhibit the same faces, $\infty\breve{P}\infty$, $\bar{P}\infty$, $\infty\breve{P}2$, $\infty\breve{P}4$, $\breve{P}\infty$ (Naumann) or PM, a^2, a^4, e^1 (Dufrenoy). M. Dufrenoy does not give this combination; of all those which he gives, the one represented by figure 80 of the second edition of his *Traité de Mineralogie*, from the lead mines of Freiberg, approaches closest to it. This would be $\infty P\infty$, $P\infty$, $\infty\breve{P}2$, $\infty\breve{P}5$, $\breve{P}\infty$, oP (Naumann), PM, a^2, a^5, e', g' (Dufrenoy). Haüy, in the second edition of his *Traité de Mineralogie*, describes a combination (Pl. 35, fig. 24) which has the same faces as the Florida crystals, except that $\breve{P}\infty$ or M is almost obliterated by the truncating facets $\infty\breve{P}2$, $\infty\breve{P}4$, $\breve{P}\infty$ or a^2, a^4, and e^1, while these are but slightly developed on the Florida crystals. As Haüy does not describe the locality from whence this form came, we do not know whether the circumstances under which it was produced were analogous to those of the springs of Bagnères de Luchon. Traces of phosphate of lead occur on the decomposing surfaces of some of the Florida carbonate of zinc, but always in small quantity and only as an earthy efflorescence.

Mines of the valley of Udias.—The minerals of zinc from the groups of mines at both sides of the valley of Udias, belong principally to three kinds: 1. carbonate or Smithsonite; 2. calamine proper, or disilicate; and 3. a peculiar hydrocarbonate. The carbonate and silicate are found more or less associated, and often so intimately mixed up that it is impossible to separate them practically. The hydrocarbonate and silicate are still more intimately associated, and, as we shall see hereafter, also often combined. The carbonate or Smithsonite has the same general character in all those mines as it has at Comillas; it is therefore unnecessary to repeat the description already given. We have also stated that the general character of all the mines of the valley of Udias is the same, so that here also it will only be necessary to describe the minerals, only specifying the mine in which any particular one was found, whenever it happens to be peculiar to one or more mines, or that its mode of occurrence offers some special phenomena.

At the San Roque mine a very curious tufaceous-looking ore is found, which is sometimes externally white, but more frequently of a dirty grayish colour, sometimes passing into a grayish yellow brown or chocolate colour. Lumps of it are most irregularly shaped, and look as if it had been acted upon by water, and worn into channels and cavities, which are filled with a yellowish brown highly soapy clay. These masses are often almost wholly composed of a pale brown silicate, which weathers yellowish white; but generally they contain lumps of a white anhydrous carbonate, which is exactly like some specimens of calc sinter. Other lumps, again, consist in great part of the carbonate, and have only a comparatively thin shell or envelope of the brown silicate. At the Esmeralda, the silicate occurs in compact massive stalagmitic flag-like or platy brown subcrystalline silicate, not unlike that which we have described as occurring in the flat veins of Florida.

The association of hydrocarbonate and disilicate of zinc may be noticed at all the mines, but may be most characteristically seen at Dolores and San Bartolome. At the latter we have considerable masses of reniform white ore, consisting of alternations of transparent fibrous disilicate of zinc with white opaque hydrocarbonate, the prismatic needles of which the shells of silicate consist, being perpendicular to the periphery of the shell, that is, radiating from the centre of the globular mass. The hydrocarbonate is found in great masses, consisting of successive layers of perfectly pure white mineral, which formed the floors of caverns such as that of Dolores, in which the fossil bones were enveloped. Fine cracks run through the mass, the walls of which are sometimes seen covered with a chocolate brown organic film when the mass breaks along those incipient joints. In some cases the surfaces of the layers of deposition are covered with a similar brown deposit, which is also in part ferruginous clay: where this occurs, the ore is quite fissile, and the surfaces sometimes exhibit fine ripple markings. The white ore must have been deposited in water as a precipitate, over the surface of which the supernatant liquor must have remained for some time, until the precipitate consolidated. Sometimes, however, the water must have drained off rapidly while the precipitate was still quite gelatinous, so that, on rapidly drying, it formed a light, very porous mineral, the surface of which became wrinkled by the shrinking of the mass as it dried. In other cases a small hollow must have got filled with a solution in which a precipitate was formed, and out of which the supernatant liquid must have drained, as from a filter in a funnel, leaving a very friable porous white mass like certain kinds of mountain meal.

The hydrocarbonate also formed stalactites consisting of concentric shells, the surfaces of contact often exhibiting beautiful dendrites, due to oxides of manganese and iron. It also formed a beautiful coralline arborescence, almost undistinguishable at first sight from *flos ferri* Arragonite. Sometimes a small stalactite of hydrocarbonate became subsequently encased by a deposit of translucent white Smithsonite.

Another form in which the hydrocarbonate occurs, is, as a kind of conglomerate, often cellular, consisting of worn bean-like fragments, soiled with ochreous clay and cemented together. This kind, which appears to have formed the rolled pebbles of a stream, was only met with in the cave of Dolores, and lay beneath the fine mud in which the fossil bones were enveloped.

Masses of pure white hydrocarbonate are frequently found covered or irregularly mixed with fibrous transparent silicate; and the latter is got several inches thick, consisting of successive layers, but there always appears to be an exceedingly fine parting of hydrocarbonate between each layer, and sometimes a layer is quite opalescent from the interposition of hydrocarbonate between the fibrillæ. This intimate mixture of the two has an interesting bearing on the question of the composition of disilicate of zinc, as we shall show hereafter.

Sometimes the hydrocarbonate is found to coat the opposite walls of a narrow joint or plane of bedding; the surfaces get warty and covered with small crystals of silicate, the warts increase so as to produce miniature stalactites, which ultimately reach the opposite wall or floor; the silicate continuing to be deposited sometimes fills up the greater part of the space between the walls. The hydrocarbonate first deposited was often perfectly laminated and became fissile; in this way the weight of the warts and miniature stalactites broke off sheets of mineral from the roof of the joint, which fell until the ends of the stalactites came in contact with the floor. The upper surface, which was a plane of lamination, now constituted a new beautifully smooth floor, upon which a coating of silicate was formed and new stalactites descended.

Another, though not so common a form, is where the hydrocarbonate is found filling up a narrow joint, as a dendritic spongy mass, exactly like the calc sinter, which is formed as a kind of pseudomorphite of moss, especially of species of Sphagnum. This variety looks as if it had been formed in an open fissure or cleft filled with moss, and, except in material, is undistinguishable from the corresponding pseudomorphites in carbonate of lime found in joints of limestone in the neighbourhood of rich springs.

The hydrocarbonate of zinc also occurs perfectly globular, some specimens being beautifully pisolithic. The balls are frequently as round as if turned in a lathe, and are composed of successive shells which are often faintly tinged by organic matter or oxides of iron and manganese at the surface of each shell; many have been found 4 to $5^{\text{cm.}}$ in diameter, some are flattened or spheroidal, and in general the large ones are so. The circumstances under which spheroids of this kind are found will be fully described in the next section.

Peculiar combinations of hydrated disilicate and dicarbonate of zinc, which will be more fully described hereafter, are found associated with hydrocarbonate of zinc, of the form which we have been just describing. These combinations are of two kinds: 1. beautifully white porcellaneous hard balls, the surfaces of some being highly polished and nacreous, which are usually agglomerated together by a paste of a similar composition, and pieces of which, when the balls fall out, form a number of exquisitely formed hemispherical cups. These balls vary from $1^{\text{mm.}}$ to $50^{\text{mm.}}$ in diameter, and are always composed of concentric shells. Pisolithic masses of these shells are found in white ore, sometimes irregularly distributed, but often filling cup-like depressions. At the San Bartolome mine, thick laminated masses of a porcellaneous compound similar to these balls are found, and also some large, more or less reniform masses composed of thin concentric shells, about $1^{\text{mm.}}$ thick, coloured on the surfaces by oxides of iron and manganese, and by organic matter of an ochreous, olive green, brownish gray, or reddish brown colour, and frequently separated by fine partings, like tissue paper, of translucent disilicate of zinc, consisting of extremely short prisms whose length is equal to the thickness of the film; the surfaces of the films, being consequently formed by the ends of those crystals, are covered with fine asperities. Large shells of this kind are not commonly met with.

The hydrocarbonate is always earthy, like all precipitated carbonates, but in one specimen from San Bartolome, which seemed to be the end of a stalactite and consisted of distinct shells, some of the layers were distinctly fibrous, exactly like the disilicate, the fibrillæ being perpendicular to the periphery of the shells. We did not find the core, and cannot therefore say whether it had been hydrocarbonate or some other mineral. The outer surface was covered with small warts, showing that the conditions of growth had changed after the formation of the outer layer. The specimen seemed to have been a pseudomorphite of the disilicate.

At San Bartolome opaque white carbonate of lead in acicular crystals occurs. These needles are arranged in spheroidal masses, some of which look as if formed of successive layers of radiating crystals, about a nucleus of some mineral, which, in our specimen, has disappeared, leaving a fine blackish brown film lining the inside of a small irregular hollow. Sometimes it would appear as if the mass consisted of twin globular masses like those of galena already described. This remarkable ore is found in the clay which occupies a part of the lode, and appears to have been worked for in Roman times.

Mines of Puente Arce.—The carbonate of zinc, or Smithsonite, from this locality, is somewhat pisolithic and peculiar; the globules and paste contain much oxides of iron and manganese, the former containing, however, much less than the latter. Many of the globules appear as if they were transitions between lachrymæ and crystals; the ends of the crystals appear to have the faces of a rhombohedron, and rhombohedral crystals of carbonate of iron occur in the zinc ore. Fine specimens of pseudomorphic Gœthite after coxcomb pyrites are found on some specimens of Smithsonite, which are mottled white and brown, as if the ore from which the carbonate was formed, consisted of an intimate mixture of blende and pyrites.

Mines of La Dobra and Puente Viesgo.—The blende of La Dobra, near Puente Viesgo, is made up of so intimate a mixture of blende and Smithsonite, that in some specimens it would be difficult to say which predominated. Carbonate of lead also appears to exist in this mixture. The carbonate of zinc exists in stellated globular or hemispherical forms, not more than $1^{mm.}$ in diameter. Red spots, as if a fine red powder had been lightly sprinkled upon it, is found upon the fresh surfaces of this curious mixture of blende and Smithsonite; this powder appears to be cinnabar.

The veinstone of the galena in the Dobra is almost identical with that at Tresviso, to be described presently: it is chiefly sulphate of barytes, which has replaced carbonate of lime.

At Puente Viesgo, the Smithsonite is white, or grayish-white, cellular and stalagmitic, like that of Merodio, to be described hereafter. The galena is blackish-gray, and extremely like some specimens of blende; the two minerals are so intimately mixed, that we could not find among the specimens which we have, a single one of either free from the other. The veinstone is a highly indurated white limestone, mixed with sulphate of barytes and calc spar, sometimes crystallized in scalenohedrons of the same kind as those found at Merodio. The blende appears to have been in great part decomposed; the galena has also undergone decomposition, earthy carbonate of lead, or cerrusite of a white colour, or sometimes tinged red, being frequently formed; the galena and cerrusite occur in pockets. The red colour of the carbonate of lead is due chiefly to the presence of a ferruginous clay which accompanies it, somewhat in the manner of a gangue. In this clay doubly terminated quartz crystals, usually clouded, are abundantly found; in the interior the quartz is slightly smoked and transparent, the clouding or white opaque part forming a shell, which is evidently due to the metamorphic action of water. Nodules of oxide of manganese with mammillated depressions in them, as if they had been formed upon the surface of mammillated zinc ore, are also found full of imbedded quartz crystals of this kind. Nodules of hæmatite, coated with pseudomorphic sulphate of barytes, after bitter spar, are also abundant. Some specimens of the cerrusite contain traces of earthy cinnabar, or native vermillion.

A green soapy indurated clay, which on exposure to the air decomposes into a highly plastic pipe-clay like earth, occurs in very thin plates among the joints of the limestone in the neighbourhood of the lode, and not more than $400^{m.}$ from the hot springs of Puente Viesgo.

At Racines a curious conglomerate of pisolithic hæmatite, carbonate of zinc in lachrymæ, of the kind to be described in the next section, and clay, etc., occurs. In the same locality is likewise found another curious conglomerate of galena, sandy clay, and some earthy manganese.

At La Cabada the blende is very dark coloured, but the quantity of iron in it is not greater than in other blendes of the district; the dark colour appears to be due to lamellar structure. The mineral is divided by a number of fine joints or cracks, which are completely filled up by crystalline sulphate of barytes, which is likewise found as a pseudomorphic veinstone after calcite. Scarcely any calamine is found at the Cabada.

Mines of Merodio.—The veinstone at Merodio was originally calc spar, enveloping blende, and largely crystallized in scalenohedrons, most of which are now converted into carbonate of zinc. Massive pieces of pseudomorphic Smithsonite, in the form of the "dog tooth" grouping of the scalenohedrons, are found completely enveloping beautiful garnet coloured blende, which in small fragments is subtransparent. One of those pseudomorphites having the form of a scalenohedron (the metastatique of Haüy, d^2 of Dufrenoy, and S_3 of Zippe), although not quite half a full form, measures $9^{cm.}$ along the terminal edges, which are very well defined, though slightly rounded. It is a shell of from $3^{mm.}$ to $5^{mm.}$ thick, of semitranslucent Smithsonite, which is partly filled up with a warty tufaceous mass of the same substance. The inner side of the shell in the part not filled up, is covered with a number of small warts. Whenever one of those more or less hollow pyramids is unbroken, a small hole may be observed in the end where it is broken off from the wall of the druse: through this the lime was removed and the tufaceous zinc introduced. A similar hole may often be seen in large crystals of felspar, which have been decomposed in the inside, or in a tooth in an early stage of decay.

The chief characteristic of the Merodio Smithsonite is the development of mammillated and reniform structure. The mineral is sometimes semi-translucent and calcedony-like, that is white, with a faint opalescent blue tint, and was deposited in extremely thin layers. Lumps of white granular limestone are sometimes enveloped by coatings of it; the limestone appears in some cases to have been removed subsequently, leaving a hollow of an irregular shape, containing only a small quantity of clay. Some of the successive layers of this semi-translucent Smithsonite have a radiated structure like silicate of zinc. The main mass is, however, a compact hornstone like Smithsonite, the surfaces of which are beautifully mammillated; the part forming the mammæ is frequently tinged yellow, and sometimes is bright lemon yellow. Occasionally pieces are found consisting of successive layers more or less mammillated, and of a leek green colour, and sometimes of a darker shade; the green portions are crystallized in acicular crystals, which form fibrous layers, and the ends of which are formed by three faces of a rhombohedron. Under a layer of these acicular crystals were found in one specimen curious fan-shaped groups of silver white talc, exactly like plumose mica. From their position there could be no doubt of their having been formed at the same time as the zinc, and therefore from solution.

The hornstone like compact Smithsonite, is frequently full of imbedded small quartz crystals, some doubly terminated and smoked; the larger number are not, however, quite perfect at one end, and only very slightly smoked: they resemble, however, very much those of Puente Viesgo above mentioned.

Sometimes the mineral is more or less scoriaceous, the cellular surfaces being always mammillated or covered with opal-like lachrymiæ, of which we shall have more to say in the next section. Dense white, more or less foliated Smithsonite, very like that found at Andarra, in the Peñas de Europa, and which has a perfectly earthy fracture like the hydrocarbonate, is also found here.

Silicate of zinc, much resembling the calcedony, like Smithsonite, and sometimes coloured blue by silicate of copper, likewise occurs, but not in large quantity. Druses lined with crystals, as at Comillas, are not found; any deposits formed on their walls consist of lachrymæ or mammæ. Galena does not occur at Merodio, but traces of sulphide of copper are found.

Mines of Tresviso.—The blende of Tresviso is massive, of a dark reddish brown colour, though in fragments it is like common garnet and subtransparent. Galena is found scattered through the blende, but so distinctly segregated, that the mine was worked for lead. The veinstone is a compact white jurassic looking limestone, which has been partially converted into sulphate of barytes in the portions immediately in contact with the blende. Smithsonite is likewise found here, and is perfectly like that of Merodio, so that it is needless to repeat the description above given.

Mines of the Peñas de Europa.—Lamellar crystallized blende of great purity and perfectly transparent, even in masses several inches thick, is found at Andarra and Peña Vieja; the colour varies from very pale lemon yellow to beautiful garnet red. This beautiful blende is found in all stages of decomposition into earthy white Smithsonite. The weathering takes place along the planes of cleavage, which are distinctly marked by the lamellar structure. Pieces of white Smithsonite formed in this way are found with a nucleus of amber yellow blende. The Smithsonite is sometimes finely granular and crystalline, at others compact with an earthy fracture, and lastly earthy like chalk. The first two are usually of a pure white colour, but sometimes having here and there a pale lemon yellow or rose tint; the latter is occasionally further developed into points of earthy cinnabar. The earthy Smithsonite has usually a very pale ochre tint, and some specimens are associated with earthy cinnabar or native vermillion.

§. 2. *Observations on the mammillated, reniform, globular, and botryoidal structure in minerals.*

While the forms of individual crystals are carefully studied, every new face, however embryonic, noted, and the crystallographic laws which govern the union of two or more of them investigated, the special structures and configurations, which are either the direct result of those crystallographic laws, or at least are influenced by them, do not receive much attention. A bare glossary of terms, with an explanation of their meaning, is generally all that is to be found in most books on mineralogy or geology upon the subject; indeed, we know of no book which has collected together the scattered observations which have been made upon the causes or manner of formation of the different kinds of structures and configurations. And yet those structures, when properly studied, afford us often the most complete evidence of the character of the chemical changes by which the minerals were produced: they are indeed to chemical changes, to a certain extent, what fossil plants and animals are to vital changes. The only branch of the subject which has been at all studied, is pseudomorphosis, for the phenomena included under that term belong to the class we are here discussing, and from the light it has helped to throw upon geological changes, the aid which the complete study of the whole subject may afford to geological theories may be judged. Many of those structures and configurations may no doubt be produced in different ways, and consequently, whenever an opportunity presents itself of observing the mode of formation in any particular way, advantage ought to be taken of it to add to our knowledge. The zinc minerals which we have examined have afforded us instructive examples of the developement of certain structures, in which fortunately all the stages could be traced.

In the geodes of the main mass of carbonate of zinc, from Stas. Lucita and Felix, we noticed some very curious oval and sometimes pear-shaped drops or lachrymæ of white translucent mineral, the surface of which had a peculiar satin lustre, not unlike that of beads of satin spar, or white fibrous sulphate of lime; they were often not bigger than a good-sized pin's head. Each lachryma appears to have generally formed upon the apex of a crystal or other projecting point, and to have arisen from the oozing of drops of water saturated with carbonate of zinc from the surface of the rock. The drop was not heavy enough to overcome the adhesion to the surface and to fall, but it became elongated so as to be attached to the roof only by a mere point. Whenever the evaporation was considerable, the solution became gelatinous, that is, whenever the amount of water in the solution did not much exceed the quantity which the substance in solution would retain in its colloid or gelatinous state. An essential condition in the formation of these drops is, that the walls be more or less dry and the solution strong at first, and that there be here and there points on the surface, so that the water which may ooze in should become spheroidal, and not run out into a mere thin film. When a geode is full of water, and the walls thoroughly wet, no lachrymæ can be formed; but, on the other hand, this is the condition favourable to the formation of crystals. When the solution was not strong enough, that is, when there was more water than could be retained by the substance after it had gelatinized, the substance began to pass into a crystalloid condition. We have examples of lachrymæ in this incipient state, when the curve of the drop begins to become two or more planes.

The passage of a substance from the colloid to the crystalloid state seems to show that when a body dissolved in water is about to assume the solid state, it first becomes spherical, that is, it takes the form of a polygon with an infinite number of sides, the edges and angles of which are gradually truncated, until two or three planes only are left. Some substances have a greater tendency to be separated from a solution in a colloid state than others; thus, carbonate of zinc is generally precipitated gelatinous, whereas nearly all silicates of zinc are thrown down crystalline—or, if colloid at first, become crystalloid gradually. Substances which cannot exist in a colloid state—and they appear to be bodies which either do not form any combinations with water, or which form a few very definite ones, while colloid ones form an unlimited number of unstable compounds—cannot produce reniform, globular, or botryoidal masses. If a substance whose colloid state is more or less stable, and whose commonest crystalline form has equal, or nearly equal, axes, forms lachrymæ which tend to become crystalline, the change into the crystalloid state appears not to proceed beyond an incipient stage, by which the embryonic edges are represented by waved lines on the surface of the drops, giving rise to satin, silk, and mother-of-pearl lustres. If, on the other hand, one of the axes be $= \infty$, that is, if the substance crystallize in a prismatic form, and if the other axes are equal, or do not differ much in relative length, so that the particles will not have to undergo much unequal compression, but can arrange themselves in lines of molecules, we have the fibrous structure. If the crystallization takes place after the substance has separated in a gelatinous form, as lachrymæ, mammæ, or botryoidal bunches, the fibres or prisms radiate from the centre, because of the tension or strain which the structure of the colloid mass imposes upon the molecules. If a gelatinous mass deposits in a crevice on the two parallel, or nearly parallel, walls without forming mammæ, there will be no strain or tension, and consequently the prismatic fibres will be of equal length throughout, and we shall have the fascicular or baccillary structure.

The solutions of those substances whose colloid condition is more or less stable, can form much larger drops than those which are not colloid at all, or which are much less so. Thus, a solution of carbonate of zinc will form a larger drop than one of silicate of zinc of the same specific gravity. If a layer of a stable colloid body partially dries before more solution comes upon it, the successive layers may be distinctly traced afterwards; but in the case of an unstable colloid body, which easily crystallizes, the molecular movement which takes place in the act of crystallization propagates itself through the successive layers, though not equally hydrated at the moment, and obliterates the layers of deposition more or less, and sometimes completely. In the latter case it will however be found, that the surfaces of contact of two layers correspond to a basal cleavage of the prism, which becomes quite marked in those minerals in which the basal cleavage is imperfect.

If the lachrymæ first formed are near each other, but yet sufficiently removed to allow of their growth for some time before contact, and if after contact the liquid continues to ooze very slowly, under circumstances where the evaporation is very slow, or where the liquid is only removed by absorption by the porous rock, new lachrymæ may be formed at the end of the first, and so on. We have thus the botryoidal structure. Some solutions apparently independent of any colloid condition are more adhesive to surfaces than others, and hence have more capillary power. Such solutions will not readily form lachrymæ, will wet large surfaces, and will not readily form elongated drops, neither will they run out readily over the surfaces of such drops previously formed. In order therefore to form true botryoidal masses, we must have a solution not having too high a capillary power, highly colloid, but unstably so. These conditions would be more frequently filled by silicate of zinc than by carbonate, hence the existence of the beautiful botryoidal silicate in the joints of the Venta before mentioned. As these conditions cannot frequently coëxist, fully developed botryoidal structure cannot be very common.

Some of the most characteristic lachrymæ, both pear shaped and globular, are found at the Vicenta. Sometimes the lachrymæ are associated with zinc bloom, which, as is well known, is produced by a sort of exudation, therefore similar to that which produces the lachrymæ. In the case of this mineral, the solution from which it would separate would not be perhaps at all colloid, and would not form pear shaped drops, but only hemispherical ones, such as all solutions of crystalloid bodies form on flat surfaces. Zinc bloom does not appear to be the result of the action of solutions on a large scale, and hence never goes beyond the stage of hemispherical warts.

When a number of lachrymæ approach each other, so that their margins fuse, we have reniform or mammillated structure. The former is produced by the lachrymæ being formed at a sufficient distance apart to allow of their growing into small nodules before they become united into a continuous mass. The mammillated structure would appear to result from the continuous or periodic wetting of the surface after the formation of the first lachrymæ or warts, by which a continuous layer of mineral, having protuberances corresponding to them, would be formed The more colloid the substance, the larger would be the drop and the more hemispherical the protuberances. Hence, while sesquioxide of iron, phosphate of alumina, and carbonate of zinc readily form reniform and mammillated masses, carbonate of lime and similar nonhydrous precipitates do not. Thin liquids containing crystalloid and noncolloid substances in solution form a succession of small drops, which produce continually lengthening stalactites, down along the surface of which the solution runs. Colloid substances being too adhesive, would not, except where produced rapidly, and in large quantity, and under very peculiar circumstances, produce stalactites; that is, the liquid would adhere to the surface and produce shells or segments of spheres or spheroids of successively increasing diameters.

In the description of the remarkable cavern of Dolores, in the valley of Udias, we mentioned the occurrence of the hydrocarbonate of zinc in a granular form upon the floor (*ante*, p. 67). This granular mineral was formed by the dropping of water from the roof of the cavern upon the floor, and as the phenomena attending its formation afford an excellent example of one of the modes of formation of globular structure, we have reserved their description for this place.

A stream flowed through the cavern, and after heavy rains appears to have periodically inundated it, leaving a thin film of soft hydrocarbonate spread over its surface when the supernatant water had drained away. Upon this soft mineral, drops of water continually fell from the roof, and gave rise to phenomena which differ in many respects from those presented during the formation of ordinary stalagmite. A succession of drops falling on the soft floor, produced a cup-shaped depression, which was enlarged by the succeeding drops. The splash of the drops threw small globules of the mud about, forming the granular mineral observed on the floor. During the dry period of the year, these granules dried and became hard, and when the dropping commenced anew, these hard grains got moved about, and had their surfaces smoothed wherever a rapid succession of drops fell; they also slowly enlarged by the gradual deposition of new matter upon them. During the period of flooding, when a new layer of mineral was deposited, these rounded globules acted as the nuclei around which deposits took place, so that they often became enlarged from the size of a peppercorn to that of bullets, and many are found consisting of successive concentric shells $50^{\text{mm.}}$ in diameter. A rapid succession of drops, not accurately falling upon the same spot, seems to have detached fragments of the more or less soft mass, or floods of water may have carried broken fragments of the mineral into the cups; and being too large to be ground into round fragments, they wore into flat lenticular or irregular pebbles. The cups thus formed were filled up by the successive deposits of mineral matter which floods brought into the cavern. But while on the level floor the hydrocarbonate was deposited in successive laminæ, the cups became the moulds of concretions. In this way, probably, the cup got filled up with soft mineral; as the water drained off, drops began again to fall into the centre of the soft mass, by which a fresh cup was produced, and this again filled up, and so on; the final result being the production of a kind of flattened spheroidal concretion, with a slight indentation in the top. Sometimes the points from which the drops fell appear to have changed, so that no new cup was formed. In this case, the last deposited matter contracted on drying, and left a slight depression, with irregular lips, not unlike an opening bud. The change in the point from which the drops fell was often very slight, so that a new cup was formed close to, but not directly over, the first one; or droppings took place at the same time from two points, so close as to produce twin cups, and afterwards twin concretions, some of which are of very considerable size.

The dropping water frequently contained silicate of zinc, which by combining with carbonate of zinc formed one of a series of very gelatinous compounds, which we shall describe more fully in the next section. This gelatinous matter, when thrown about, formed globules much more readily than the hydrocarbonate; the granules were also harder when dry, and were easily polished by attrition when they had become hard. Some of the silicated balls, however, contain so large a nucleus of the translucent opal-like compounds of silicate and carbonate of zinc, to which allusion has just been made, that we must suppose them to have been formed by the falling of large drops of water holding silicates in solution into a solution of carbonate of zinc. Sometimes a cup-like depression, formed as above described, got filled with silicated balls, around which a gelatinous mass of the same composition accumulated; in this way a pisolithic mass was formed. One specimen from San Bartolome, consisting of part of the floor of a very large empty space or small cavern in the lode there, afforded a most beautiful example of this kind of formation; the globules are formed of a beautiful white porcellaneous mineral, very smooth, and set in a hard milk-white paste, which is filled with a number of exquisite hemispherical depressions when the balls are removed, as mentioned in the last section. This specimen shows that the phenomena of dropping water, exhibited by the large cavern of Dolores, can also take place in the smallest fissures.

Sometimes the amount of silicate which got into solution of carbonate was so considerable, that the entire deposit on the floor consisted of a combination of both. As all those compounds appear to exist only in a colloid state, and to be able to combine with an unlimited number of equivalents of water, they must have formed very stiff gelatinous masses, which produced globules with great facility whenever water splashed upon them. If such a surface were exposed to a rain of drops of water, nearly the whole mass would have become pisolithic, and some specimens from San Bartolome seem to have been formed in this way.

§. 3. *Chemical examination of some of the minerals of Zinc and Lead of the Province of Santander.*

Blende and Galena.—We have sufficiently described the peculiarities of structure and occurrence of the blende from the different mines in a previous section, and here, therefore, it will be only necessary to discuss those of composition. The following table contains the results of the analyses of characteristic specimens from two localities of the higher ranges:

ANDARRA.					TRESVISO.				
Zn . . .	66·467		ZnS . . .	99·162	Zn . . .	64·996		ZnS . . .	96·968
Mn. . .	0·010		MnS . . .	0·017	Mn. . .	0·012		MnS . . .	0·019
Fe . . .	0·135		FeS_2 . . .	0·291	Fe . . .	0·197		FeS_2 . . .	0·423
CaO . .	0·172	=	$CaOSO_3$.	0·418	CaO . .	0·504		CaO,SO_3	1·226
MgO . .	0·081		MgO,SO_3	0·240	MgO . .	0·196	=	MgO,SO_3	0·579
S	33 005				S	32·665		BaO,SO_3	0·048
				100·128	BaO,SO_3	0·048			
	99·870								99·263
						98·618			

The specimen from Andarra was of a beautiful lemon colour, almost perfectly transparent: all the outer surfaces were removed by cleavage so that the fragment analyzed was perfectly free from weathering; no flaw or cleavage fracture could be discovered in it, and yet, when finely powdered and boiled with water for a few minutes, sulphuric acid could be detected in the water. On this account, as well as the presence of sulphate of barytes, in the blende of Tresviso, we have calculated the lime and magnesia as if they were present as anhydrous sulphates. The presence of lime and magnesia as sulphates, or at all events in some form in such beautifully transparent and unaltered blende, is very curious, and explains the facility with which it decomposes and passes into Smithsonite along the planes of lamination. Their presence is equally significant in regard to the mode of formation of the blende, as we shall more fully discuss in the next section. The specimen of blende from Tresviso was selected with equal care in order to avoid weathered surfaces or incipient joints containing sulphate of barytes.

In a specimen of a curious blende-like galena from Puente Viesgo the same association of the alkaline earths with lead, appears to exist, as the following analysis shows:

Pb . . .	82·006		PbS . . .	94·676
Zn . . .	0·336		ZnS . . .	0·502
Mn . . .	0 008		MnS . . .	0·014
Fe . . .	0·055		FeS_2 . . .	0·119
CaO . . .	0·344	=	$CaoSo_3$ . .	0·836
MgO . .	0·131		MgO,SO_3 .	0·385
S	13·225		BaO,SO_3 .	3·481
BaO,SO_3 .	3·481			100·013
	99·586			

We endeavoured to ascertain in all these cases whether the lime and magnesia were present as carbonates by dropping acid upon the powder, while the result was watched with a strong lens, but we were unable to detect any effervescence.

We did not detect any traces of cadmium in any of the specimens examined by us.

Smithsonite.—The following table shows the composition of an average specimen of the massive grayish white Smithsonite from Merodio, free from quartz crystals:

ZnO . . .	61·986		ZnO,CO_2 . .	92·716
FeO. . . .	1·997		$2ZnO,Si_2O_2HO$	2·819
MnO . . .	0·314		FeO,CO_2 . .	3·218
CaO . . .	0·381		$MnOCO_2$ . .	0·468
MgO . . .	0·056	=	CaO,CO_2 . .	0·679
Si_2O_2 . . .	0·718		MgO,CO_2 . .	0·115
CO_2 . . .	34·442			100·015
	99·894			

The amount of iron and manganese is very variable, some specimens of mammillated Smithsonite from Merodio often containing not more than 0·25 per cent. The Smithsonite found north of the Dobra range, nearly all of which occurs in the dolomite, usually contains much more iron than the ores of that chain, or of the Peñas de Europa. The whole or the greater part of the iron has there too very generally passed into the condition of peroxide. The following numbers represent the composition of a specimen of red calamine, formed in thin plates, from the Esmeralda mine. The mineral was very compact, and broke with an earthy fracture:

ZnO . . .	57·371	ZnO,CO_2 . .	88·514
Mn_3O_4 . .	0·648	Mn_3O_4 . . .	0·648
Fe_2O_3 . . .	7·939	Fe_2O_3,HO . .	8·832
CaO . . .	0·538	CaO,CO_2 . .	0·952
MgO . . .	0·065	MgO,CO_2 . .	0·135
Si_2O_2 . . .	0·953	SiO_2 . . .	0·953
CO_2 . . .	32·658		
	100·167		100·034

Some of the iron in this ore may exist in the state of carbonate of the protoxide, and another part as a silicate of the sesquioxide, but the greater part is certainly hydrated peroxide. The preceding table would also represent the general composition of the massive dolomitic looking subcrystalline red Smithsonite of Comillas, Udias, etc., except that a still larger proportion of their iron may be considered to be carbonate of the protoxide.

Wherever carbonate of zinc is formed in limestone, north of the Dobra range, it usually contains much less iron than the dolomitic ore. But as the limestone underlying the dolomite is always more or less earthy, leaving, when dissolved in dilute acids, a spongy skeleton of silicate of alumina and other bases, similar to that left by all earthy limestones, the grayish white Smithsonite formed in it usually leaves a similar skeleton. This is not so much the case with the sinter like more or less red ore found in joints and along the planes of bedding, as in the concretionary nodules, and masses formed apparently by substitution in the mass of the rock itself. The following numbers represent the composition of such a nodule, to which reference was already made at p. 87, and of its spongy skeleton:

WHOLE MINERAL.				SKELETON.	
ZnO	56·117	ZnO,CO_2 . .	86·580	CaO . . .	1·175
MnO	0·480	MnO,CO_2 . .	0·777	MgO . . .	0·537
FeO	3·210	FeO,CO_2 . .	5·171	MnO . . .	0·100
CaO	0·883	CaO,CO_2 . .	1·577	FeO . . .	4·692
MgO	0·007	MgO,CO_2 . .	0·015	Al_2O_3 . .	12·105
CO_2	33·300	Skeleton . .	6·122	SiO_2 . . .	80·044
Spongy skeleton	6·122			Alkalies and loss	1·347
			100·242		
	100·119				100·000

Hydrocarbonates of Zinc.—Analyses of the peculiar hydrocarbonate of zinc which occurs in the various mines of the valley of Udias under the circumstances so fully described in previous sections, have been already published by M.M. T. Peterson and E. Veit,[13] and M. A. Terreil.[14] The former believe that it has not a constant composition. They have proposed the formula

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[13] Annal. d. Pharm. u. Chem. Bd. cviii. 48. [14] Compt. rend., t. xlix. p. 553.

$8ZnO,3CO_2,6HO$, to express the results obtained as a mean of several analyses of a portion taken from the centre of a large piece. The following table contains those results:

	Calculated.	Found.
$8ZnO$	73·021	73·1
$3CO_2$	14·838	15·1
$6HO$	12·140	11·8
	99·999	100·0

Exposed to the air for three months, they found its composition to be then represented by the formula $3ZnO,CO_2,2HO$, according to the following numbers:

$3ZnO$	75·277	74·73
CO_2	13·597	13·81
$2HO$	11·124	11·45
	99·998	100·09

The following are the results of an analysis of a ball of hydrocarbonate, made by M. Terreil:—

ZnO	68·15
CO_2	13·17
CaO	1·60
Al_2O_3,Fe_2O_3	0·80
HO	12·40
Hygroscopic water	3·13
Organic matter containing nitrogen	traces
	99·25

This corresponds, according to him, to the formula $5ZnO, 2CO_2,3HO$; but as part of the water is hygroscopic, he prefers the formula $3ZnO,CO_2,2HO$. If we deduct the lime, alumina, iron, and hygroscopic water, and calculate the composition of the remainder in 100 parts, and also calculate the theoretical composition in 100 parts from the formula $3ZnO,CO_2,2HO$, we get the following numbers:—

	Calculated.	Found.
$3ZnO$[15]	75·277	72·716
CO_2	13·597	14·052
$2HO$	11·124	13·230
	99·998	99·998

These numbers differ too much to warrant us in accepting the formula proposed by M. Terreil as the true one.

M. Terreil states, that even at 200° Cent., hydrocarbonate of zinc loses only hygroscopic water. This statement appears singular, especially when we recollect the interesting results of M. Damour,[16] who found that even the zeolites, with the exception of analcime, possess the property of losing considerable quantities, and sometimes even the whole of their hydrated water, either when placed in a perfectly dry atmosphere, or when exposed to temperatures comprised between 40° Cent. and incipient redness, and of again taking it up. The loss of water which hydrates sustain when heated, depends not only upon the temperature to which they are exposed, but likewise upon the relative facility with which the air in contact with them is changed, and upon the duration of the exposure. In order to test this point, the percentage of water and carbonic acid in a piece of perfectly white compact hydrocarbonate was determined by the loss which it sustained by ignition, in its air-dried state, after an hour's exposure to a temperature of 130° Cent. in an oil-bath, and after an exposure of five or six hours to a temperature ranging between 150° to 180° Cent., and with frequent exposure to the air. A similar experiment was tried with a fragment of pure white friable bergmehl-like hydrocarbonate. The following table contains the results of these experiments:—

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[15] Equivalent of zinc=32·6.

[16] Compt. rend., t. xliv. p. 975.

	Compact Mineral.	Friable light Mineral.
Total HO, and CO_2 in air-dried mineral . . .	25·738 . .	28·380
Loss in one hour at 130°	2·041 . .	3·151
Loss in six hours at 150° to 180°	14·423 . .	18·571

The following table represents the relative composition at each stage:

	Compact Mineral.			Friable light Mineral.		
	Air-Dried.	Dried at 130°.	Dried at 150° to 180°.	Air-Dried.	Dried at 130°.	Dried at 150° to 180°.
ZnO	74·262	75·809	88·898	71·620	76·121	92·302
CO_2 HO	25·738	24·191	11·102	28·380	23·879	7·689
	100·000	100·000	100·000	100·000	100·000	100·000

These experiments show that not only does hydrocarbonate of zinc lose hydrated water at temperatures under 200°, but even a considerable quantity of carbonic acid. It is even probable, that in a current of hot air at a temperature of 180° Cent., it would be fully decomposed. It may, however, be safely dried at the temperature of boiling water, or even as high as 120° Cent., provided it be not too long exposed to the heat.

With the view of determining whether the composition of the hydrocarbonate is always constant, a large number of specimens, exhibiting as great a variety of structure and origin as possible, were examined. In some cases the sum of the water and carbonic acid was determined by ascertaining the loss by ignition; but in several cases every constituent was separately determined, and great care was especially taken in estimating the amount of carbonic acid. The following contains the description of the specimens, and the results of the analyses:—

I.—Compact indistinctly laminated mass, with its upper surface covered with ripple marks; colour, pure white, opaque; dull, earthy, but with a slightly conchoidal fracture, and fissile along the planes of deposition; somewhat brittle, streak shining. Hardness = 2. Specific gravity, 2·232, or 3·758 after it has become fully saturated with moisture. The piece examined was taken from the centre of the mass, which was twelve centimetres long, ten wide, and eight thick.

II.—Fragment taken from the exterior of the last-mentioned mass, which had been many months exposed to the air.

III.—Light, porous, friable mass, of a perfectly white colour, and not unlike some kinds of meerschaum, but much more friable, being easily reduced to powder between the fingers.

IV., V., VI.—Specimens of compact white hydrocarbonate, similar to I. and II.

VII.—Compact white hydrocarbonate, very distinctly laminated, and slightly discoloured from clay, etc., on the surfaces of the laminæ; formed part of the floor in which the bones were buried.

VIII.—Another specimen of light, friable sinter, similar to III., but having a faint rose-red tint.

IX.—Fragment of the hydrocarbonate encasing a piece of bone. Some of the layers, though perfectly opaque, had a fibrous structure, like silicate of zinc.

X.—Part of a lump of pure white compact hydrocarbonate, enclosed in translucent crystalline Smithsonite.

XI.—Part of a lump of pure white compact hydrocarbonate, intermixed with white transparent fibrous silicate of zinc.

XII.—External layer of a stalactite, having a distinctly fibrous structure, analogous to that of the silicate.

XIII.—Ball of white hydrocarbonate of zinc, one centimètre in diameter.

	I.		II.		III.	
Oxide of zinc	74·059		74·244		73·581	
Lime	0·011		0·013		0·010	
Phosphate of iron	0·008		0·005		0·003	
Alkalies in combination with silica	0·003		—		—	
Carbonic acid	14·934	25·968	14·893	25·656	14·980	26·42
Hydrated water	10·070		10·027		10·421	
Hygroscopic water	0·964		0·736		1·028	
Organic matter	traces		traces		traces	
	100·049		99·918		100·023	

	IV.	V.	VI.	VII.	VIII.
Oxide of zinc	74·173	74·262	74·247	74·092	73·427
Carbonic acid Hydrated water Hygroscopic water	25·827	25·738	25·753	25·908	26·573
	100·000	100·000	100·000	100·000	100·00

	IX.	X.	XI.	XII.	XIII.
Oxide of zinc	74·222	74·284	74·391	74·437	74·480
Carbonic acid Hydrated water Hygroscopic water	25·778	25·716	25·609	25·563	25·520
	100·000	100·000	100·000	100·000	100·000

We generally consider that hydrated gelatinous precipitates have the composition which the analyses of the bodies formed by throwing them upon filters, pressing and drying the filtered masses, give us; there can be no doubt, however, that all substances capable of existing in the colloid condition form an almost endless succession of hydrates; so that if we represent any colloid body by A, its hydrates may be represented by the general formula $mA + nHO$, where m and n are simple numbers. In the preceding section we mentioned that one chief distinction between crystalloid and colloid bodies, was that the former either did not combine with water at all, or formed with it a small number of definite compounds. Between the truly colloid and crystalloid bodies we have a third class of substances which combine with water, and partaking of the character of the former two; with the colloid they agree in forming a succession of unstable hydrates; with the crystalloid, in forming one or more moderately stable ones. To this class of bodies belong those precipitates which are thrown down in a hydrated earthy state. The Spanish hydrocarbonate is a good example of this kind of precipitate, and may, no doubt, be obtained in different states of hydration. And as we know that in bodies which contain several equivalents of hydrated water, each equivalent may not always be held with the same amount of force, such hydrates gradually tend by losing water to attain their state of greatest stability. What is the composition of that one? Messrs. Peterson and Veit appear to think that $3ZnO,CO_2,2HO$ is that one. Their formula for the fresher mineral, $8ZnO,3CO_2,6HO$, corresponds with, if it was not suggested by, that proposed by Schindler for the precipitate, which is thrown down when hot or cold solutions of sulphate of zinc and carbonate of soda or potash are mingled. If we consider the water driven off at 120° as part of the hydrated water, the composition of No. 3 would, to some extent, agree with the formula; to some extent only, however, for the water, which in an air-dried specimen is more likely to be in excess, is too small. But as it is only the friable porous variety, which must contain most hygroscopic water, that agrees with this formula, while all the compact varieties differ materially from it, we could not, even if we had not what we believe to be positive evidence that part of the water is hygroscopic, adopt the formula $8ZnO,3CO_2,6HO$.

How are we to look upon those hydrocarbonates? Are they compounds of hydrated oxide of zinc and of carbonate of zinc, or are they basic carbonates combined with water? If the former, Schindler's formula should be written thus: $[3(ZnO,CO_2)+5(ZnO,HO)]+HO$: if the latter, $8ZnO,3CO_2+6HO$. In the former case the water performs two functions, and one equivalent must be held with much less force than the other five. The latter would be a very anomalous kind of compound. The most stable hydrate of oxide of zinc must obviously be that represented by ZnO,HO; accordingly we find that, in the majority of hydrocarbonates yet discovered, the sum of the equivalents of carbonic acids and water is equal to the number of equivalents of oxide of zinc. May it not be that the body examined by Schindler was not perfectly dry; and that its real composition was $3(ZnO,CO_2)+5(ZnO,HO)$?

If we consider the part of the water which is driven off in the water bath as hygroscopic, the formula just stated would represent the composition of the Spanish hydrocarbonate. The following table, which contains the results of the analyses I., II., III., from which the hygroscopic water, lime, etc., have been deducted, shows the agreement between the composition calculated from the formula and that deduced from experiment:—

	CALCULATED.		FOUND.					
			I.		II.		III.	
8ZnO . . .	74·529		74·759		74·869		74·337	
$3CO_2$ . . .	15·144	25·469	15·075	25·240	15·020	25·131	15·134	25·662
5HO . . .	10·325		10·165		11·111		10·528	

A hydrocarbonate of zinc from Marion County, Arkansas, has been described by Dr. W. Elderhorst under the name of Marionite,[17] which appears to be identical both in composition and the circumstances under which it occurs with the Spanish mineral. A specimen of the mineral was found to have the following composition:—

ZnO	73·262
CO_2	15·010
HO	11·808
	100·080

Dr. Elderhorst has also evidently followed Schindler, and proposed the formula $8ZnO,3CO_2,6HO$. The carbonic acid agrees perfectly with our formula, while the water is considerably below what Schindler's formula would require, while it would be more likely to be in excess. It is probable that the mineral was not fully dried. We may here remark that all the specimens of the Spanish mineral examined by us were thoroughly air dried, having been in a dry, warm room during more than eight months, and had all consequently arrived at the stage of greatest stability, whatever may have been the original degree of hydratation.

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[17] First Report of a Geological Reconnoissance of the northern counties of Arkansas, made during the years 1857 and 1858, by David Dale Owen, Principal Geologist, assisted by William Elderhorst, Chemical Assistant, Edward T. Cox, Assistant Geologist. Little Rock, 1858, p. 153.

Messrs. Peterson and Veit give 3·52 as the specific gravity of the Spanish hydrocarbonate of zinc; while M. Terreil gives 2·042. The following observations will, we think, explain the discrepancy. A piece of No. I., when allowed to absorb water completely, was found to have the density 3·758; the quantity of water absorbed was 18·189 per cent. If we consider that before absorbing this quantity of water it had first displaced it, the specific gravity of the mineral, supposing it to have absorbed nothing, would therefore be 2·232. According to Smithson, the specific gravity of zinc bloom is 3·59.

The original substance to which the name zinc bloom or zinc blüthe was given, and which consists of a species of efflorescence which forms on the walls of zinc mines and upon the rubbish taken out of the workings, appears to be a different compound from that which we have been describing. Smithson first, we believe, analysed a specimen of this mineral in small mammiform patches from Bleiberg in Carinthia. Another analysis of it was made by Dr. Carl Schnabel,[18] with a specimen which had effloresced upon the rubbish at Ramsbeck, in Westphalia, under the influence of strong sunshine. Similar efflorescences are found upon a curious blende, which occurs in globular and reniform masses, formed of concentric layers at the Venta, near Comillas, specimens of which we have analysed; and also upon some Smithsonite from the mines of Florida. These different specimens agree very well in composition, and may be represented by the formula $3ZNO,CO_2,3HO$. The white compound which forms upon metallic zinc, when moistened and exposed to the air, appears to belong to the same category, as the following table, containing the results of all the analyses, shows:—

	Calculated.		Venta.	Bleiberg (Smithson).		Ramsbeck[19] (Schnabel).		Artificial Compound (Bonsdorff).	
$3ZnO$	71·311		71·260	71·4		71·210		71·25	
CO_2	12·880	28·687	28·740	13·5	28·6	13·677	28·790	14·19	28·750
$3HO$	15·807			15·1		15·113		14 56	
	99·998		100·000	100·0		100·000		100·00	

In this formula the sum of the equivalents of carbonic acid and water exceeds the number of equivalents of oxide of zinc, and consequently the objections urged against Schindler's formula apply here with equal force. We had not, however, enough of the mineral to determine the carbonic acid separately, or whether a portion of the water could be driven off at a lower temperature than the rest. It would be useless to discuss the matter further until the whole of the compounds of oxide of zinc with carbonic acid and water, obtained by precipitating salts of zinc by means of carbonates, by the rusting of zinc, etc., shall be reëxamined. It is interesting, however, to find that the natural compounds obtained by precipitation and by efflorescence, exhibit exactly the same difference as the artificial ones, and furthermore, that the corresponding natural and artificial bodies are identical in composition.

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[18] Pogg. Annal., cv. 144.

[19] We have deducted the foreign matters and hygroscopic water, and reduced the residue to the standard of 100 parts.

Pisolithic Amorphous Silicates of Zinc.—We shall first speak of the pisolithic silicates, the formation of which we have fully described at pp. 92–101. Some of those balls are opaque, and consist of beautifully concentric shells; but nearly all that we have examined contained a semi-translucent opal-like nucleus, often not bigger than a pin's head, but sometimes as large as the largest-sized peas; sometimes spheroidal balls, as large as beans, of this opalescent silicate, are found. These opalescent nuclei and balls are not, like the opaque ones, composed of concentric layers, but appear to be quite homogeneous. The concentric structure, as well as the opacity, may, perhaps, in some cases be explained as a process of drying or dehydratation, and not as a successive growth; in favour of this view is the fact, that the opalescent nucleus has generally somewhat more water than the opaque external shell. The crystalline lenses of fishes' eyes, when preserved in spirit of wine, or when immersed in hot water, show a similar concentric structure. In some cases this explanation does not certainly apply; for the nucleus has a different composition from the opaque shells, and the latter have all the appearance of having been successively formed about the former, the external surfaces of some of the shells having different lustres, for instance. The following are the results of the analyses of several of these balls:—

I. Slightly spheroidal ball, $12^{mm.}$ in diameter; colour, enamel white; surface dull; fracture like biscuit porcelain.

II. Slightly spheroidal ball, not found as a nucleus, but may have been originally in a large ball; lustre resinous, inclining to vitreous; fracture conchoidal and shining; colour, milk-white; semi-translucent; brittle; sp. gravity, 3·694; not unlike opal, but not iridescent.

III. A remarkably round ball, 6 to $7^{mm.}$ in diameter, pure enamel-white; surface smooth, exactly like glazed porcelain or fused white enamel; fracture like biscuit porcelain.

IV. Ball of about the same size as No. II., but having a dull surface; colour, enamel white; fracture like biscuit porcelain.

V. A pea, $5^{mm.}$ in diameter, taken from the centre of a large ball $10^{mm.}$ in diameter; external surface smooth, like fused enamel; fracture like biscuit porcelain; colour, pure enamel white; streak white; hardness, 3·5; sp. gravity, 2·883. It contained in the centre a semi-translucent nucleus, about the size of a mustard seed, of the density and other properties of No. III.

	I.	II.	III.	IV.	V.
ZnO	68·780	64·549	61·865	62·266	66·844
CaO	0·240	0·006	traces.	0·001	traces.
Mgo	0·015	traces.		——	„
MnO	0·002	——	——	——	——
FeO with PO_5	0·007	0·003	0·002	0·003	0·002
Alkalies	traces.	traces.	traces.	traces.	traces.
SiO_2	8·950	6·493	8·292	9·214	17·471
CO_2	16·180	11·246	11·301	10·101	4·637
HO	10·675	17·672	18·624	19·362	10·834
	99·849	99·969	100·084	100·947	99·788

M. Terreil also examined one of those silicious balls; it had the specific gravity 2·762, and appears to have been analogous to No. IV. in other respects. As he could not remove the carbonate by means of very dilute acetic acid without also decomposing the silicate, he concluded that the two were in chemical combination. The specimen he examined contained 12·92 per cent. of water, of which 5·16 per cent. was driven off between 100° and 200° per cent.; he accordingly reckons this part as hygroscopic water. Considering silica to be a teroxide, he assumes the formula $[ZnO,SiO_3, (ZnO,HO)_3]_2 + ZnO,CO_2$. This is a very complex formula, in which we have to assume the combination of silicate of zinc with hydrate of zinc, and the combination of this compound with anhydrous carbonate of zinc. We also believe that the carbonate is in combination with the silicate; but having had a greater variety of specimens to examine, we have, as we believe, arrived at a simpler expression of their composition. The following are the formulæ which we propose for the compounds examined by us:—

I.— $2\,ZnO,SiO_2 + 5\,(2\,ZnO, CO_2) + 8\,HO$.
II.— $2\,ZnO,SiO_2 + 3\,(2\,ZnO, CO_2) + 9\,HO$.
III.— $2\,ZnO,SiO_2 + 2\,(2\,ZnO, CO_2) + 8\,HO$.
IV.—$2(2\,ZnO,SiO_2) + 3\,(2\,ZnO, CO_2) + 14\,HO$.
V.—$2(2\,ZnO,SiO_2) + 2\,ZnO, CO_2 + 4\,HO$.

The following table shows the accordance between the theoretical composition calculated from the formulæ and the results found:

I.

	Calculated.		Found.	
$12\,ZnO$	69·563		69·299	
SiO_2	4·404		8·979	
$5\,CO_2$	15·734	26·032	15·965	26·720
$8\,HO$	10·298		10·755	

II.

	Calculated.		Found.	
$8\,ZnO$	64·598		64·549	
SiO_2	6·165		6 493	
$3\,CO_2$	13·126	29·235	12·246	28·918
$9\,HO$	16·109		16·672	
			99·960	

III.

	Calculated.		Found.	
6ZnO	62 365		61·865	
SiO	7·936		8 292	
$2CO_2$	11·264	29·697	11·301	29·925
8HO	18·433		18·624	
			100·082	

IV.

	Calculated.		Found.	
10ZnO	61·515		62 266	
$2SiO_2$	9·398		9·214	
$3CO_2$	10·000	29·090	10·101	29·463
14HO	19·090		19·362	
			100·943	

V.

	Calculated.		Found.	
6ZnO	66·996		66 844	
$2SiO_2$	17·051		17·471	
CO_2	6 056	15·956	4·637	15·471
4HO	9·900		10·834	
			99·786	

Nothing can be simpler than the connection which these formulæ establish between the composition of the different balls, According to them, they are compounds of two bodies, which are already well known, and one of which abounds in the locality, namely, calamine or hydrated disilicate of zinc, and a dicarbonate of zinc, which may be precipitated by sesquicarbonate of soda from a solution of sulphate, and which has been obtained by Boussingault combined with water as $2(2ZnO,CO_2) + 3HO$, and by Schindler as $2ZnO,CO_2 + 2HO$. All the conditions for the formation of such a dicarbonate in the presence of a solution of silicate of zinc, coëxist in the mines where those peculiar compounds are found. If these formulæ be correct, dicarbonate of zinc and disilicate of zinc are isomorphous;[20] and these compounds are analogous to those formed by bisulphate of potash and bichromate of potash, sulphate of potash, and chromate of potash, and the nitrates of potash and silver; and consequently similar compounds may be formed in endless proportions; so that the whole series may be represented by the general formula:

$$m\,(2ZnO,CO_2) + n\,(2ZnO,SiO_2) + p\ HO.$$

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[20] See App., p. 175; "On some curious molecular changes produced in disilicate of zinc, and some of its compounds with carbonates, by the action of heat", for an account of some curious phenomena which appear to corroborate this view in a very remarkable manner.

This power of combining in endless proportions appears to us not only to show that hemimorphite and dicarbonate of zinc are truly isomorphic, but that the isomorphism of carbon and silicon extends to carbonic and silicic acids, and this adds an additional support to the view that silicic acid is a deutoxide.

Fibrous Hemimorphite, or Hydrated Disilicate of Zinc (*Calamine*).—After discovering the simple relationship of the formulæ of the balls containing different proportions of water, the idea at once suggested itself to us that the isomorphism of the disilicate and dicarbonate might explain the want of atomic relation of the water, which is almost invariably observed in all the specimens of calamine that have hitherto been analysed. In order to test this hypothesis, we analysed a specimen of perfectly colourless (and in small pieces transparent) fibrous hydrated disilicate of zinc, which is associated with the hydrocarbonate from San Bartolome mine. This specimen was found to contain carbonic acid, as will be seen by the following table:—

ZnO	67·792
SiO_2	23·424
CO_2	1·421
HO	7·263
	99·900

If we look upon the carbonic acid as existing in a compound $2ZnO,CO_2,HO$, that is, in a corresponding degree of hydration to that in which disilicate of zinc is found, the proportions in which the silicate and carbonate exist in the mineral will be found to be, in 100 parts:—

$2ZnO,SiO_2,HO$	92·702
$2ZnOCO_2,HO$	7·298
	100·000

7·298 of this hydrocarbonate would contain:—

ZnO	5·296
CO_2	1·421
HO	0·581
	7·298

If we deduct these numbers from those given above in the table of the results of the analysis of the mineral, we shall get the following proportions, which represent the quantities of oxide of zinc and water which belong to the silicate, as distinguished from those which belong to the carbonate:—

ZnO	62·596
SiO_2	23·424
HO	6·682
	92·702

Or in 100 parts, and compared with the composition of disilicate of zinc calculated from the formula $2ZnO,SiO_2,HO$:—

	Calculated from the Formula.	Calculated from the Analysis.
$2ZnO$	67·213	67·523
SiO_2	25·409	25·268
HO	7·377	7·207
	99 999	99·998

The ratio between the number of equivalents of silicate and carbonate deducible from the preceding calculations is about 11 : 1; so that the pure white fibrous silicate may perhaps be classed in the same category as the silicious balls, and the formula $11(2ZnO,SiO_2,HO)+ZnO,CO_2,HO$, assigned to it. In this case we have distributed the water between the two constituent compounds; but we have not done so in the former, as it may be that the water is in two conditions.

Almost every specimen of hydrocarbonate of zinc contains some silicate; but we cannot assume in every case that they are in combination. Indeed it would appear that the peculiar combinations which we have described above are exceptional, and are only formed by direct precipitation, and that in all other cases where silicate of zinc is found in hydrocarbonate, it is either simply mixed with it, or part of the water is displaced by silicic acid subsequently penetrating the mass. The following analysis of a specimen of stalactite from Dolores Cavern will serve as an example apparently of mere mixture.

ZnO	72·410	=	$2ZnO,SiO_2,HO$	5·376
FeO	0·301		$8ZnO,3CO_2,5HO$	92·359
MnO	0·028		FeO,CO_2	0·484
CaO	0·382		MnO,CO_2	0·045
MgO	0·087		CaO,CO_2	0·682
SiO_2	1·370		MgO,CO_2	0·179
CO_2	14·791			
HO	10·115			99·125
	99·484			

The ratio of silicate and hydrocarbonate approximates to 1 : 5, but the two are obviously merely mixed. In some thick stalagmitic masses from San Bartolome, we have complete evidence of this mixture, the two constituent minerals appearing as if columnar, that is, a multitude of drops of silicate fell upon a floor upon which hydrocarbonate mud was periodically deposited. The mammillated masses of silicate too, as was described in a previous section, exhibit partings of hydrocarbonate.

The following analysis of a specimen of the peculiar moss-like hydrocarbonate described at p. 91, affords an example of the apparent displacement of water by silica:—

ZnO	64·560
FeO	3·420
MnO	0·520
CaO	0·571
MgO	0·015
CO_2	16·263
SiO_2	6·187
HO	7·680
	99·226

If we were to look upon this substance as a combination of disilicate and dicarbonate, we might assign it a formula which would harmonise perfectly with those given above, as the following table will show:—

$2ZnO,SiO_2$	22·474	=	8ZnO	70·943	70·535
$2ZnO,CO_2$	61·371		$3CO_2$	14·441	14·314
HO	7·680		SiO_2	6·737	6·759
			4HO	7·877	8·390
MnO,CO_2	0·841				
FeO,CO_2	5·510				
CaO,CO_2	1·020				
MgO,CO_2	0·031				
	98·927				

But this formula of $2ZnO,SiO_2 + 3(2ZnO,CO_2)+4HO$, is in reality the ordinary hydrocarbonate $8ZnO,3CO_2,5HO$, in which one of SiO_2 has apparently combined with two of oxide of zinc. This particular case shows that it is probable that many compounds of disilicate of zinc and of hydrocarbonates may exist besides the many definite ones with the dicarbonates which we have described above, and consequently, that the variation in the proportion of water in fibrous hemimorphite, may be explained in many cases, as well by supposing the presence of other hydrocarbonates as by that of the dicarbonate.

Silicated hydrocarbonates appear to exist at Wiesloch also, as the analyses of ores from that locality published by C. Riegel[21] show.

Botryoïdal hydrated disilicate of Zinc.—At p. 88 we have described a curious globular silicate of zinc found in the flat vein of Florida mine. This mineral consisted of an irregular mass, sometimes distinctly botryoïdal, the largest of the globules being about a centimètre in diameter. Externally the globules were covered with asperities, which were the ends of crystals disposed in a radiated acicular form. The fracture of a globule showed the cleavage planes of these crystals, arranged in a stellated form, and inclined to each other. These cleavage planes were large, and appeared to be ∞P∞, parallel to which the cleavage is complete. Colour, yellowish-brown; the fresh surfaces being studded with a number of extremely small black points. The cleavage planes had a mother-of-pearl lustre, which soon tarnished and became dull; sp. gr. 3·267. When freshly fractured, and a perfectly undecomposed fragment examined, its hardness was nearly = 5. The mineral decomposed into a brownish-yellow ochry substance with remarkable facility. Its composition was found to be:—

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[21] Archiv. d. Pharm. (2) Bd. lviii. p. 29, quoted by Bischoff, Lehrbuch der chemischen Geologie 2ter Bd. p. 1883.

ZnO	62·195
SiO_2	24·883
Fe_2O_3	5·182
CaO	trace
HO	7·121
	99·381

If we deduct the oxide of iron, and calculate the proportions in 100 parts of the oxide of zinc, silica, and water, alone, and compare the results with the theoretical composition deduced from the formula $2ZnO,SiO_2,HO$, we shall find that the silica and water are too high in the experimental results, and consequently the oxide of zinc too low. In what state is the sesquioxide of iron in this mineral? Is it in combination, or merely mixed mechanically with it? The property which silicate of zinc has of dissolving in a solution of caustic potash, suggested itself at once as a means of answering this question. On treating the mineral in the state of fine powder with a solution of potash in the cold during several days, the whole of the silicate of zinc was dissolved, and a reddish-brown powder was left, the composition of which may be represented by the formula $2Fe_2O_3,SiO_2,HO$. This is exactly the silicate of iron, which is found in Glauber's iron-tree, obtained by putting a piece of dried protochloride, sesquichloride, or protosulphate of iron, in a solution of silicate of potash:—

$$3(2Fe_2O_3SiO_2) + 2(KO,CO_2).$$

This would, in all probability, be the silicate formed by the mutual decomposition of an alkaline silicate and sulphate, or bicarbonate of iron.

The great facility with which this mineral decomposes, its behaviour in acids, and its peculiarities generally, would seem to show that the silicates of zinc and iron are in some sort of combination, and not simply intermixed. If from the whole we deduct not merely the oxide of iron, but also the amount of silica and water combined with it, the remainder will contain oxide of zinc, silica, and water, in the proportions represented by the formula $2ZnO,SiO_2,HO$.

In the next section, the results of an analysis of a specimen of silicate of zinc from San Roque will be given, from which it would appear that silicates of iron, no doubt of variable composition, appear to be mixed up with the silicate of zinc generally. In some of the massive ores from Florida, small stellated crystals of apparently the same compound as the botryoïdal mineral just described, are met with.

Perhaps many other minerals containing peroxide of iron, etc., would present us with a like phenomenon, if we could dissolve one constituent like the silicate of zinc. There are, no doubt, many cases where foreign substances cannot be considered to be merely mechanically mixed in a mineral, and yet cannot be held to replace some constituent isomorphically, which may be explained in this way. Indeed, it is probable that many of the so-called isomorphic replacements are in reality such compounds, held by a very feeble affinity, but which, unlike the one here in question, cannot be dissected.

Effect of the Zinc Solutions on the Fossil Bones.—The occurrence of bones in so unusual a deposit as hydrocarbonate of zinc, made it interesting to determine whether phosphate of lime would precipitate zinc, that is, whether a pseudomorphite of phosphate of zinc, after phosphate of lime, would be produced readily. Only a few of the bones found in the Dolores cave, as described at p. 66, came into our possession, and they were chiefly fragments. Some were wholly enveloped in the white mineral, others only partially. Among the latter was a tibia, apparently belonging to some ruminating animal, probably a large-sized deer. This bone had lain on the floor, and was covered from time to time with water holding a salt of zinc in solution, whenever the cave was flooded. On one side was a partial stalagmitic coating, apparently produced by droppings from the roof. It was beautifully white; the dense part of the bone adhered strongly to the tongue, like burnt bone; it was, however, much more fragile, and friable. Even when kept for several days over oil of vitriol, it lost a considerable quantity of water, which appeared to be chemically combined with it. The cancellated tissue of this bone was beautifully preserved. A portion of this tissue was put for three or four days into acetic acid diluted with about twice its weight of water, in order to dissolve out the carbonates which it contained; this process was repeated once with fresh acid, somewhat stronger, so as to insure the total removal of the carbonates. Sulphide of hydrogen in excess, added to the acid solution, gave a copious precipitate of sulphide of zinc; this was removed by filtration, and oxalate of ammonia added to the filtered solution, which threw down a precipitate of oxalate of lime. This shows either that the whole of the carbonate of lime was not removed from the bone during the action of the solution of zinc, or that new carbonate of lime had been formed from the phosphate by the substitution of oxide of zinc. The tissue treated with the acetic acid was washed repeatedly with distilled water, and boiled with it, in order to remove all traces of the acetates of zinc and lime, and then dissolved in hydrochloric acid. To this solution ammonia was added in excess, and it was then digested for some hours, so as to insure the re-solution of all the phosphate of zinc thrown down at first. On filtering, the phosphate of lime remained on the filter; the filtered liquid contained any zinc existing as phosphate; on adding sulphide of ammonium to the solution, a precipitate of sulphide of zinc was thrown down. The solution filtered from the precipitate of sulphide of zinc, treated with chloride of magnesium, gave a precipitate of ammonio-magnesian phosphate. On determining the amount of zinc in the precipitated sulphide in the usual way, and calculating the amount of phosphoric acid in the ammonio-magnesian phosphate, the results showed that the phosphoric acid and oxide of zinc were in the proportions to form the salt $3ZnO,PO_5$. In the air-dried bone, the amount of oxide of zinc as phosphate was 6·090 per cent., equivalent to 10·805 per cent. of $3ZnO,PO_5$. The amount of lime thus substituted by zinc appeared to vary according as the bone was completely enveloped or not, and according to the part of the bone examined. The solid part of a fragment of a small bone, completely enveloped by a coating of hydrocarbonate about $5^{mm.}$ thick, contained a quantity of oxide of zinc equivalent to 16·98 per cent. of phosphate of zinc. A part of the carbonate of lime may have been derived from this substitution. Scarcely a trace of the organic matter of the bone had been preserved, but in those which were covered by layers of hydrocarbonate, the inside of the coating or shell of mineral, when removed from the bone, had always a yellowish-brown superficial colour, and bore an accurate imprint of the bone. When the inner layer of such a coating was dissolved slowly in moderately dilute acetic acid, brown membranaceous flocculi floated about, which were probably the remains of the periosteum. This would seem to show that the bones were not much decayed before they were enveloped in the hydrocarbonate of zinc, and consequently confirms the view that the formation of the upper layers, at least, of the hydrocarbonate of zinc in the cavern, was contemporaneous with the species of animals to which the bones belong.

§. 4. *Order of succession according to which the different kinds of ore were formed, and their probable geological age.*

It is not our intention to discuss the general question of the origin of mineral veins; what we propose to do is merely to briefly summarize a few of the more obvious conclusions which we think may be drawn from the whole study of the ores, regarding the order of their successive formation and the geological periods at which they were produced.

In our mineralogical description of the ores of the different mines, we have given evidence enough of the formation of Smithsonite from blende, carbonate of lead from galena, and hydrated peroxide of iron from pyrites. A portion at least of the carbonate of zinc, both of the limestone and dolomite mines, is the result of the oxidation of blende; but some of the Smithsonite seems not to have ever been changed into blende; that is, we have a primitive carbonate and a secondary one derived from the oxidation of blende. It is probable that the Smithsonite in the lower part of the Vicenta mine (described at p. 59) is primitive: in the upper part the ore consists of reniform and stalagmitic pyrites; lower down this passes into blende, and still lower into Smithsonite. As this mine, like all the others in the province, disappears in depth, and is more metalliferous at the top, we may safely assume that the supply of metallic matter came from above, and any metamorphosing actions must have followed the same direction. The curious lode of Sitio de la Trecha (described at p. 74), the upper part of which alone was blende, intermixed with carbonate of lead, galena, and cinnabar, and the lower and larger part Smithsonite, seems to give us another example of primitive carbonate. The isolated pockets of ore, too, at the Venta (p. 56; see also "Transverse Section of the Sta. Lucita Mine", Pl. 6), are apparently primitive carbonate which lay out of the course of the sulphurizing waters.

The carbonate of zinc, and perhaps also the carbonate of lead, was originally precipitated from solution by carbonate of lime or dolomite. In some instances the replacement was so complete that the Smithsonite passes insensibly into pure dolomite, as at the Venta (p. 56), and still more strikingly at the Vicenta (p. 59), and Reocin (p 69). Both the carbonate of lime and of magnesia appear to have taken part in the decomposition, but the carbonate of magnesia, as the more soluble, appears to have been wholly removed, while some of the carbonate of lime filled up joints and formed a kind of conglomerate, such as the irregular masses found imbedded in clay at the Numa, and also, but not so frequently, at San Bartolome, consisting of pebbles of brown micaceous sandstone and rounded polished nodules of brown hæmatite. An immense number of similar rounded nodules of hæmatite occur in a crystalline limestone paste, containing some magnesia, filling up the joints of the dolomite at Angel de Toporias. Wherever a joint is accompanied by a fault, the walls have slickensides, and the dolomite for a certain distance was crushed. This crushed rock was generally recemented by a slightly reddish-brown paste, like that just described as filling the joints of the Angel de Toporias. This paste usually contains some zinc, and sometimes also lead. The following analyses show the composition of the pure gray dolomite, and the composition of the paste and fragments composing a piece of such a brecciated dolomite having a well-marked slickenside.

I. Crystallized hard gray dolomite.		II Dolomitic breccia treated with acetic acid.			
		a Soluble part.		*b* Insoluble part.	
$CaCo_2$ . . .	56·088	CaO,CO_2 .	89·500	CaO,CO_2 . .	48·967
$MgOCO_2$ . .	39 121	MgO,CO_2 .	6·429	$MgOCO_2$ . .	42·873
FeO,CO_2 . .	3·417	Fe_2O_3 . .	2·800	FeO,CO_2 . .	5·423
MnO,CO_2 . .	0·186	Mn_3O_4 . .	0·188	MnO,CO_2 . .	0·076
$CaOSO_3$ . .	0·680	PbO,CO_2 .	0 088	$(3CaO)PO_5$ . .	0·251
$(3CaO)PO_5$.	0·250	ZnO,CO_2 .	0·265	CaO,SO_3 . .	0·580
SiO_2	0·320	Water and loss	0·730	SiO_2 . . .	0·320
	100·062		100·000	Fine ferruginous clay containing spangles of mica	0·874
					99·864

The ratio of the carbonates of lime and magnesia in the crystallized dolomite may be represented by $9CaO,CO_2+7MgO,CO_2$, while the part insoluble in acid was true dolomite CaO,CO_2+MgO,CO_2. The carbonate of zinc in this paste is small in quantity, but in other specimens of dolomite it reaches from one per cent. to complete replacement.

The comparatively large quantity of carbonate of protoxide of iron in the dolomite affords a simple explanation of the difference between the Smithsonite of the limestone mines and that of the dolomite ones, and at the same time strikingly confirms the view that these rocks were the original precipitants of the metals. The carbonate of zinc of the limestone is white because the latter contains scarcely any iron, while that of the dolomite is red because that rock contains iron, which is converted into peroxide during the slow precipitation of the zinc. Hence, too, there are no iron ores (hæmatite or pyrites) at Merodio or Tresviso, while both of them abound at Comillas and Ciguenza. Most, if not all, the iron ores (hæmatites and pyrites) of the province were probably originally derived from the decomposition of the dolomite.

There are many reasons for supposing the blende and galena to have been produced by the metamorphosis of primitive carbonates. At the Emilia mine, as we have already stated (p. 87), the blende and dolomite pass into each other exactly as the latter and the carbonate do. It is not easy to account for this penetration, unless we suppose that the zinc was introduced as carbonate, and was subsequently converted in sulphide. The analyses of the blendes of Andarra and Tresviso, and of the galena of Puente Viesgo (p. 102–103), taken in conjunction with the partial conversion of the veinstone into sulphate of barytes, where it is in contact with the mineral at Tresviso, appear to us to completely prove the secondary origin of the blende. The existence of lime and magnesia probably as sulphate in the centre of pieces even of the perfectly transparent lemon-yellow blende of Andarra, and the presence in addition of sulphate of barytes in the garnet blende of Tresviso and the blende-like galena of Viesgo, show that the ore was deposited from water containing sulphates and sulphides of the alkalies and alkaline earths, such as those of the thermal springs of Aix la Chapelle or Bagnères de Luchon. It may be objected, that sulphate of barytes could not be formed from waters containing sulphides and sulphate, and that barytes could only be brought in such quantities into veins as carbonate or chloride, and afterwards changed into sulphate. The actual deposition of crystallized sulphate of barytes, sometimes containing strontian mixed with cube-octohedral crystals of pyrites upon cariated quartz at Bagnères de Luchon, sets the question completely at rest however. It affords a conclusive argument that the metals which form stable sulphides would be deposited as such, while the alkaline-earthy metals would be deposited as sulphates. On this account we believe the analyses of the blendes and the galena above mentioned to be of great interest.

The occurrence of stalactitic blende and of small capsules full of crystals of blende at Comillas, shows clearly that new blende has even been formed simultaneously with the oxidation of older blende; the stalactitic and reniform blende and galena of the Florida mines are obviously derivatives of ancient carbonates, although now again in process of oxidation. The total absence of any trace of silver in this reniform galena supports this view. The conversion of carbonates into sulphides, and of the latter into the former, appears to have been alternating phenomena in many of those mines, and no doubt are so everywhere under certain circumstances. Thus, at Florida solutions containing sulphates were circulating in the joints and fissures which afterwards were mineralized, as is proved by the honeycombs of barytes which afterwards become the nuclei of Smithsonite. While the pseudomorphites and sulphate of barytes after dolomite and calc spar, coating Smithsonite in one place, and new blende in another, show not only that that substance is connected with the formation of sulphides, but that it may make its appearance in neighbouring mines at different periods. In connecting sulphate of barytes with the formation of metallic sulphides, we do not of course imply that that salt may not be present in waters containing no trace of sulphides.

The oxidation of blende and galena has apparently been effected by means of salts of iron and manganese, more probably carbonate, but occasionally also by sulphates, and in the presence of carbonates of the alkaline earths. When solutions of protosalts of iron and protocarbonate of manganese, dissolved in carbonic acid, are exposed to the air, they absorb oxygen with great rapidity, and after a time the sesquioxide of iron is precipitated as hydrated peroxide, if the salt be a carbonate, and the manganese generally as deutoxide. Before this takes place, however, the solution has very oxidizing powers, and if brought into contact with sulphide of lead, zinc, copper, or iron, they transfer the absorbed oxygen to the sulphide, which becomes a sulphate. This, if carbonate of lime or magnesia be present, is at once decomposed, carbonates of the denser metals and sulphate of the alkaline earth being produced. A very small quantity of iron is able to effect this oxidation under favourable circumstances. If there be a good deal of manganese in the solution, and that the access of oxygen is rapid, peroxide of manganese will be permanently precipitated. The spongy or vascular tissue of oxide of manganese found filling the hollows left in Smithsonite by the removal of crystals of galena, which we described at p. 85, afford a beautiful example of the changes just described. The caries too, which was noticed at p. 86 in crystals of carbonate of zinc, was evidently produced by a solution containing protoxide of manganese, absorbing oxygen while in contact with the crystal, by which its manganese was precipitated as deutoxide, and the acid which was combined with it corroded the surface of the zinc crystal. The black powder of MnO_2 dotted over the surface of the caries is a witness of the character of the change. These two metals, whose protoxides always tend to pass into higher and more stable oxides, and the carbonates of whose protoxides are soluble in water containing carbonic acid, while their higher oxides do not combine with that acid, but such of them as are naturally formed are insoluble both in the hydrated and anhydrous states, and which form basic, insoluble salts with other acids, are, perhaps, the greatest oxidizing agents of the sulphides of the metals known.

Bischoff seems to think that the metals of most mineral veins have been derived from silicates originally dispersed through rocks. Whatever may be the value of this opinion—and there is much in favour of it—the silicates of zinc of Santander belong to the newest ores, if they are not indeed in many cases the last compounds formed. Some of the silicated ores of San Roque afford valuable evidence on this point. The ore of that mine consists of a curious mixture of silicate, Smithsonite, and hydrocarbonate of zinc. At p. 89 we described the general character of the silicate, and it is therefore unnecessary to repeat the description here; but we may add one remark, that the mixture of carbonate and silicate is very irregular: in general, however, the silicate encloses the carbonate, but, as the following analyses prove, it has more or less penetrated the whole mass. The first table represents the results of an analysis of a specimen of a chocolate-coloured, fine-grained mass, which weathered externally to a yellowish white, earthy, though still hard substance, the results of the analysis of which are given in Table IV. The surface of the mass was worn into hollows and rounded projections, exactly like water-worn lumps of limestone. Enclosed in this brown silicate were light brown nodules, more or less irregular in form, and appearing to pass gradually into the general mass: that is, they were not like pebbles enclosed in a paste of a different substance, but rather the result of the imperfect metamorphosis of a previous more or less uniform mass. Table II. contains the results of the analysis of some of those nodules. In the centre of the same mass was a spheroidal lump, which was evidently a portion of the original substance before it underwent the metamorphosis which produced the brown ore. It consisted of a porous sinter exactly similar to what is deposited by springs rich in carbonate of lime, and, but for the material, would be undistinguishable from many specimens of calc sinter. Table III. contains the results of an analysis of this substance.

I.—Chocolate-coloured silicate from San Roque.

ZnO	63·067	=	$2ZnO,SiO_2\ HO$	94·027
Mn_2O_3	0·247			
Fe_2O_3 Al_2O_3	2·334		Silicate of alumina, iron, etc., with a small portion of carbonate of lime	5·920
CaO	0·215			
MgO	0·013			
SiO_2	25 249			
CO_2 and HO	8·828			
Alkalies	traces			99·947
	99·953			

II.—Light brown nodules enclosed in the preceding.

ZnO	62·407	=	$2ZnO,SiO_2,HO$	74·641
MnO	0·245		ZnO,CO_2	19·041
FeO	1·990		MnO,CO_2	0·396
Fe_2O_3	1·478		FeO,CO_2	3·206
Al_2O_3	0·201		Fe_2O_3 Al_2O_3	1·679
CaO	0·453		CaO,CO_2	0·808
MgO	0·108		MgO,CO_2	0·225
SiO_2	19·018			
CO_2 HO	14·162			99·996
	100·062			

III.—Nodules of white zinc sinter, forming the centre of the lumps of silicate.

ZnO,CO_2	62·947	=	$2ZnO,SiO_2,HO$	7·228
MnO	0·180		ZnO,CO_2	89·611
FeO	1·008		MnO,CO_2	0·291
CaO	0·640		FeO,CO_2	1·624
MgO	0·031		CaO,CO_2	1·142
SiO_2	1·825		MgO,CO_2	0·064
CO_2 HO	33·498			99·960
	100·129			

IV.—Yellow, apparently weathered external parts of silicious ore.

Entire substance.

ZnO	49·548	$2ZnO,SiO_2$ HO = 73·871	
SiO_2	18·822		
HO	5·501		
KO	0·239	Part soluble in chlor-hydric acid, exclusive of silicate of zinc	12·844
NaO	0·115		
CaO	0·493		
MgO	0·259		
MnO	0·040		
FeO	0·584		
Fe_2O_3	2·057		
Al_2O_3	2·412		
Cl	0·008		
SO_3	0·010		
SiO_2	5·656		
HO	0·971		
KO	0·207	Part insoluble in chlor-hydric acid.	13·413
NaO	0·177		
CaO	0·527		
MgO	0 259		
FeO	0·793		
Al_2O_3	2·353		
SiO_2	9·097		
	100·128		

Soluble and insoluble silicates together.

KO	1·698
NaO	1·112
CaO	3·884
MgO	1·972
MnO	0·152
FeO	5·244
Fe_2O_3	7·834
Al_2O_3	18·147
Cl	0·030
SO_3	0·038
SiO_2	56·186
HO	3·698
	99·995

Silicates insoluble in acid.

KO	1·545
NaO	1·324
CaO	3·930
MgO	1·935
FeO	5·917
Al_2O_3	17·545
SiO_2	67·827
	100·023

Hydrated silicates soluble in acid.

KO	1·860
NaO	0·895
CaO	3·838
MgO	2·016
MnO	0·311
FeO	4·546
Fe_2O_3	16·015
Al_2O_3	18·779
Cl	0·062
SO_3	0·077
SiO_2	44·036
HO	7·560
	99·995

The silicate of alumina in the first analysis, was in fact a kind of clay which had to be fused with barytes to decompose it completely. In No. II. the alumina and part at least of the sesquioxide and protoxides of iron existed as silicates; it is on this account that we did not calculate the sesquioxide of iron as a hydrate. The distribution of acids and bases which we have attempted in these analyses, is of course to be understood as an approximation, which has the merit at least of representing to the eye the general character of the ores, better than where the bases and acids are given separately.

In the description of the different mines, we have frequently mentioned the occurrence of clay as a kind of gangue in the lodes, and sometimes filling up joints in the neighbouring rock. This clay is usually ochreous, and in some mines, as at Stas. Lucita and Felix and the Vicenta (p. 59), it is jointed like the dolomite, and looks as if it was derived from its decomposition *in situ*. At Puente Viesgo it is more or less of a pinkish flesh colour and highly plastic. At Venta la Vega, in the valleys of Ciguenza and Reocin, deposits of ochreous clays containing nodules of hæmatite, and often of Smithsonite, occupy the bottoms of the valleys, and are evidently connected with the clays of the lodes. The ore of San Roque was enveloped in a clay of this kind, of the colour of Oxford ochre, very soapy. A portion of it, filling up a hollow in a piece of the silicate, of which we have described the composition above, yielded on analysis the following results:—

Entire Substance.

ZnO	6·907	$2\,ZnO,SiO_2\,,HO$ = 10·297	
SiO_2	2·623		
HO	0·767		
KO	1·145	Part soluble in chlor-hydric acid, exclusive of the silicate of zinc	74·629
NaO	4·203		
CaO	0·565		
MgO	0·115		
Mn_2O_3	0·139		
$Fe_2\,O_3$	10·998		
$Al_2\,O_3$	21·104		
Cl	0·015		
SO_3	0·149		
S,O_2	29·296		
HO	6·900		
KO	0 251	Part insoluble in chlor-hydric acid	15·276
NaO	0·223		
CaO	0·429		
MgO	0·244		
FeO	0·595		
Al_2O_3	3·487		
SiO_2	10·047		
	100·222		

Soluble and insoluble silicates together.

KO	1·552
NaO	4 992
CaO	1 105
MgO	0·399
FeO	0·661
Mn_2O_3	0·154
Fe_2O_3	12·894
Al_2O_3	27·352
Cl	0·016
SO_3	0·165
SiO_2	43·760
HO	7·674
	100·724

Silicates insoluble in acids.

KO	1·648
NaO	1·460
CaO	2·810
MgO	1·599
FeO	3·899
$Al_2\,O_3$	22·832
SiO_2	65·772
	100·020

Hydrated silicates soluble in acids.

KO	1·534
NaO	5·631
CaO	0·757
MgO	0·154
Mn_3O_4	0·186
Fe_2O_3	14·736
Al_2O_3	28·278
Cl	0·020
SO_3	0·199
SiO_2	39·255
HO	9·245
	99·995

The quantity of soda in this clay is very remarkable, but as it was present as a silicate it could not have been there accidentally. We had no opportunity of determining whether the whole mass of clay in the lode was equally rich in soda.

Similar clays are found as a gangue in a great many mines: for instance, at the zinc mines of Moresnet, near Aix la Chapelle, and at those of Tarnowitz, at the iron mines of Voulte, the lead and zinc mines near Liége, and are some way connected with the formation of the minerals. These clays are usually highly hydrated silicates of alumina, which have received different names, but which as a group are usually known as Halloysites. When pure, they become almost transparent in water, fatty and soapy rather than plastic, and are wholly decomposed by acids. Sometimes these compounds contain very little alumina, and are almost hydrated silicates of iron, such as the Nontronite of Montmort, and the Pinguite of Wolfenstein. Some of them are of a pistachio green, or some other shade of that colour, while others are of a rose colour, due to silicate of manganese. At Puente Viesgo both colours are found, as was above mentioned. The hydrated part of the San Roque clay corresponds in composition to some Halloysites, among others to that of Montmorillon, except that it is not so highly hydrated. We have already remarked, however, that gelatinous hydrates are very unstable, and that the amount of water which they contain diminishes when long kept in a very dry place. There is, however, an essential difference between our clay and a true Halloysite: it is not all soluble in acid; the insoluble part, however, bears a small proportion to the hydrated part. In general composition the San Roque clay resembles alluvial mud, except that a much larger proportion of the former dissolves in acids than of the latter; the relative proportion of alumina, too, is higher than in the finest inundation mud.

The clay of the weathered silicate of zinc, as well as that contained in the unchanged ore itself, is evidently the same as this yellow soapy clay. But while 83·008 per cent. of the latter dissolves in acid, only 48·916 per cent. of the clay of the weathered ore is soluble. The yellow clay, then, must have undergone much chemical action; and of this we have evidence, besides the degree of hydratation, in the smaller amount of silica and the relatively larger proportion of alumina as well as the remarkable quantity of soda. The latter phenomenon appears to throw considerable light upon the changes which took place at San Roque. The zinc sinter shows that springs rich in carbonate of zinc communicated with the fissures and joints forming the lodes. Other springs appear likewise to have communicated with them, which brought up considerable quantities of fine silt from the underlying clays, or they formed "swallow holes" into which streams of muddy water filtered through narrow joints which effectually barred the entry of sand or gravel. This fine mud got mingled up with the sinter, and either yielded soluble silicates to convert the carbonate of zinc into silicate, or, what is more probable, the water from which the zinc was deposited contained alkaline carbonates which acted upon the clay and dissolved out silicate, which more or less penetrated the mass, even where the clay did not reach, as is shown by the analysis of the San Roque sinter. The supply of zinc may have afterwards ceased or taken a new direction consequent upon the change in the physical geography of the district, and the silicate enclosing clay at first formed, may have in turn been slowly dissolved out, leaving the clay which, during the action of dissolution, would have necessarily become more hydrated. It is probable, however, that the whole mass of clay in a fissure was never cemented by zinc, and that the alkaline waters which deposited the zinc dissolved out silica from the clay, enriching it with soda, and raising the relative per-centage of alumina. This sort of action would explain perfectly the formation of the opaline doubly terminated crystals of quartz which are abundantly found in the clay of Viesgo. Waters containing alkaline carbonates would naturally also dissolve out lime, magnesia, and protoxides of iron and manganese; the two latter being, however, precipitated gradually as higher oxides as soon as they became exposed to the air.

If such chemical changes were to continue long in action, the clay would ultimately become altogether hydrated, and true Halloysites would be formed wherever there would not be much iron, or where the conditions would be favourable to the reduction of the sesquioxide so as to enable water to carry it off as carbonate of the protoxide. The alkalies, too, would be gradually removed by dialytic action. It is probable that some Halloysites may have had a different origin, may, for instance, be the result of the metamorphosis of igneous rocks. Some of the veins of greenish soapy clay at Viesgo suggest such an origin. No igneous rocks have, however, as yet been noticed in the province. The whole character of the clay of San Roque, the presence of minute spangles of mica, and other properties, appear to us sufficient to prove that it is a kind of inundation mud.[22] Another circumstance which favours this view is the comparative absence of such clays in the higher ranges, where little or no mud could be washed into the fissures of the rock.

But the hypothesis that these clays were brought in as mud by water is supported by physical as well as chemical evidence.

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[22] M. Jutier, in his extremely interesting observations (Note sur les résultats au point de vue Géologique des Travaux de captage des Sources Minérales des Plombières.—Annal. des Mines, 5me série, t.xv., p. 547), on the Halloysite of Plombières, considers that substance, as well as all similar substances, to be the result of a deposit derived from the waters which have traversed granite and decomposed it. If we understand him rightly, it would be a compound formed by the union of silica with alumina and other bases dissolved out of granite and other rocks, whereas we believe it to be a chemically altered clay, mechanically washed into the fissures. At page 549 he says: "The deposits of Halloysite have been formed at an epoch altogether recent and almost contemporaneous. In fact, we found in the ancient alluvions, immediately beneath the Roman works, a reddish clay which is nothing but a Halloysite badly purified". This observation completely supports the view we have taken. In connecting the red clays of the valley of Plombières with the Halloysites, he is also in accord with our view regarding the relation between the clays of the lodes and the clays of the valleys of Udias, Ciguenza, etc., stated above. On the whole, there is a very interesting concordance between the results of M. Jutier upon incipient lodes at Plombières, and those at which we have arrived after the study of fully formed mineral veins.

About half way between the town of Comillas and the Puente Portillo, and close to where a mine called Josephina was opened in the dolomite, there is a "swallow hole" in which a stream flows that issues out at the contact of the dolomite and overlying limestone at the Puente Portillo. The underlying dolomite is more or less decomposed, while the overlying limestone is more or less dolomitised. From the relative position of the two rocks, any fine mud carried into the engulphed stream would penetrate into the joints of the dolomite, and the finest, and consequently the most hydrated, may have reached the fissure forming the Josephina mine. To the east of Puente Portillo, in the high ground directly south of Stas. Lucita and Felix, another stream is engulphed in the overlying limestone, and is thought to come out on the shore of the bay at the mouth of the little river which flows under Puente Portillo, where a deposit of a highly ferruginous sinter is formed. It must, therefore, flow through the dolomite and across the lode of Stas. Lucita and Felix, with which it perhaps communicates, and if so, into which it must have borne fine mud and sesquioxide of iron, resulting from the decomposition of the dolomite. Again, in the dyke of red ochreous clay mentioned at p. 76, and to which allusion will again be made subsequently, we have the strongest evidence that the clay was carried into the joints by water in the boulders of limestone imbedded in the clay (see "Cross section of principal mines at Tresviso, Europa mountains", Pl. 15).

It only remains to speak of the hydrocarbonates of zinc. As this mineral may be said to be peculiar to a very few localities, the province of Santander, Marion County, Arkansas, and Wiesloch, in Baden, attaining its greatest development in the former locality, while in the latter place it occurs only mixed up, as at San Roque, with silicate and Smithsonite, its genesis seemed at first difficult. In reality, however, it may be easily explained. It was formed both from Smithsonite and blende, and simultaneously with the former. Wherever the decomposition of blende into carbonate took place so slowly that the carbonate was molecule by molecule precipitated, as fast as the decomposition proceeded, by carbonate of lime or of magnesia, and consequently under circumstances where there was always an excess of carbonic acid, anhydrous Smithsonite was formed. But where the decomposition took place in the presence of a large quantity of water, that is, where the carbonate was precipitated regularly from a relatively considerable quantity of solution, and where, consequently, there would be a deficiency of carbonic acid, hydrocarbonate was precipitated, just as it would happen in a laboratory. It is probable that this mineral may be indifferently thrown down, whether it exists in solution as a carbonate, sulphate, or other salt, or whether it be precipitated by carbonates of the alkalies or alkaline earths. The intermixture of silicate of zinc with the hydrocarbonate almost universally, and the association of the peculiar clays above described, seem, however, to point to silicates of the alkalies as the precipitant, and the zinc is also, no doubt, present sometimes as a sulphate. If we suppose basic silicate of potash or of soda to be added to a solution of carbonate of zinc in water, the carbonic acid of the latter, unless where the water would be highly charged with that gas, would not be sufficient to carbonate the whole of the alkalies, and consequently the most complete conditions for the formation of hydrocarbonate would coëxist in such a case. As silicate of zinc is comparatively soluble in water, especially when carbonic acid is present, and as the carbonate of zinc would, except under very peculiar circumstances, be always greatly in excess of the silicate, the latter would not always be precipitated along with carbonate, but would remain in solution until the water became saturated with it, when it would form a fine film of crystals, or it may drain away and slowly deposit as hemimorphite somewhere else. There is not a single peculiarity of the ores of Udias and San Bartolome,—the layers of hydrocarbonate separated by films of silicate, the peculiar compounds of both, even the presence of small quantities of hydrocarbonate in all hemimorphite,—that is not explained by this view.

In the Dolores cavern, and the extraordinary cavity of the San Bartolome mine, we have abundant evidence that the hydrocarbonate was precipitated from a solution, and there accordingly we find it in largest masses. The comparative absence of silicates in the Dolores cavern may be explained by the fact, that the mineral was in reality not so much formed there as brought in as inundation mud; while the circumstances of San Bartolome fully explain the extraordinary variety of the associated hydrocarbonate and silicate. Hydrocarbonate is never found at Merodio, or in the higher limestone ranges, because the rocks are too jointed and the sides too precipitous to allow of water being retained as in the dolomitic region—a condition which is likewise unfavourable to the existence of rich clays. Now this dryness, as we have shown, is favourable to the production of mammillated carbonate, and unfavourable to that of crystallised minerals, as we have shown in our section upon the structure of minerals; and the character of the ores of Merodio and Tresviso fully bears it out.

The sinter of San Roque, and the remarkable quantity of soda in its clay, seem to point to the action of thermal springs.

M. Daubrée[23] has endeavoured to establish a connection between the deposits formed by thermal springs and those of mineral veins. More recently, Mr. Hermann Müller,[24] following out a suggestion of M. Daubrée, has endeavoured to study the relations between the thermal springs of Marienbad and Carlsbad and the mineral veins of Western Bohemia. The results obtained are extremely promising, and indicate a new field for observation. The province of Santander appears to us to afford many examples of such a connection. We have already mentioned the existence of several hot springs in the province. Here we may enumerate all those which are well known, their ascertained temperature, and general chemical character. Going westward from the Biscayan frontier, we have: Solares, temp. 27°·50 Cent.; Lierganes, saline, temp. 20° Cent.; Alceda and Ontaneda, sulphurous, temp. 28°·75 Cent.; Puente Viesgo, acid, temp. 35° Cent.; Las Caldas, acid, temp. 37°·5 Cent.; Puente Nansa, sulphurous, temp. 26°·25 Cent.; La Hermida, saline, temp., spring on left bank of the Deva, 52°·5 Cent.; spring on the right bank, 56°·25 Cent.[25] An interesting circumstance about these springs is, that, leaving out Solares and Puente Nansa, they are all more or less connected with the Dobra range, and increase in temperature going westward from Lierganes, which has a temperature of 20° Cent., to La Hermida, which reaches 56°·25; the increasing temperature corresponding to the increasing upheaval and disturbance of the rocks.

Anciently such springs may perhaps have been more numerous than now, and a careful investigation of the springs of the province may hereafter lead to the discovery of many cold mineral springs which formerly were warm. The peculiar sulphate of barytes of La Florida certainly points to the former existence of a sulphur spring. Two of the existing warm ones analogous to those of Bagnères de Luchon appear to be certainly connected with lodes. At p. 75 we have mentioned the existence of veins of green soft talcose clay in the limestone at Puente Viesgo, and their apparent connection with the pinkish flesh coloured clay which forms the matrix of the ores found not more than 400$^{m.}$ from the spring. But the best example of a connection between thermal springs and mineral lodes, is that of the dyke of ochreous clay out of which the springs of the Hermida seem to arise (see p. 76). At Osuña this dyke is certainly mineralized, and there is every reason to believe that it is the same dyke which constitutes the mineralized ground of Tresviso. This is perhaps the most satisfactory example of the connection known. It is to be regretted that we possess no proper analyses of the waters of the Hermida springs. According to the work already quoted, they contain chiefly common salt, and no mention is made of alkaline carbonates.

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[23] Annal. de Mines, 5me serie, t. xii. 1858, p. 227.

[24] Cotta's Gangstudien, Bd. iii. S. 261.

[25] The temperatures are given from *El Tratado completo de las Fuentes Minerales de España*, per El Excmo. Sr. Dn. Pedro Maria Rubio. Not having the book ourselves, we are indebted for an extract from it to M. Louis Ratier, Physician, of Santander. Unfortunately the analyses given are of little value; it is even impossible to make out clearly from them to what class the waters belong.

Having established the succession of the ores, we shall conclude with a few observations upon their geological age. We may safely assume that the ores are newer than the rocks in which they are situated. At first sight the succession of clays, sandstones, and limestones, accompanied by dolomite, and a certain resemblance between some Wiesloch ores and those of San Roque, led us to suppose that we had to do with the muschel-kalk and variegated sandstone, and accordingly in the paper on the composition of the ores, read to the Royal Irish Academy, we suggested this opinion, but only as a mere guess, expressing a hope that we would be able to establish the true relations of all those beds at another time. In the preceding pages we have endeavoured to fulfil that promise, and we may now safely say that the ores are at all events later than the jurassic period; but how much later is a question which we shall now endeavour to answer.

In a memoir presented to the Institute, M. Rivière stated that the dolomite was cretaceous; that the ores of zinc lay between the dolomite and a deposit of ferruginous clay, and were contemporaneous with the cretaceous rocks, constituting in fact true beds. We give in a note the words of M. Rivière, in order to show more clearly his point of view.[26] The details which we have given in the preceding pages clearly prove that this view of the metalliferous deposits of Santander is incorrect, and that they are certainly posterior to the rocks in which they occur.

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[26] Comptes rendus, t. xlvii., No. 18, 1858, p. 728. The following passages fully explain M. Rivière's views:—"Dans la province de Santander, les dépôts calaminaires s'étendent, sur le prolongement en Espagne des Pyrénées maritimes, depuis les environs de Saint-Sébastien jusqu'aux montagnes des Asturies. Pris dans leur ensemble, et abstraction faite de quelques accidents dont je parlerai plus loin, ils constituent une suite de dépôts interrompus çà et là, mais qui, reliés entre eux par la pensée, représentent une couche métallifère formée en grande partie d'une série d'amas-couches sur un même horizon géologique, quoique se montrant à différents niveaux; par exemple, tantôt aux bords de la mer et dans les vallées, tantôt sur les parties élevées de cette contrée montagneuse. Dans l'espace indiqué, la couche calaminaire est donc plus ou moins métallifère de distance en distance; aussi n'est-elle fructueusement exploitable que sur certains points. L'horizon géologique des dépôts calaminaires se trouve parfaitement tracé par des couches dolomitiques et par une couche argilo-ferrugineuse. Ainsi les couches dolomitiques couronnent les dépôts calaminaires, tandis que ceux-ci reposent sur la couche argilo-ferrugineuse, qui est au reste plus constante, plus dévelopée et plus régulière que les dépôts calaminaires. Ces

The discovery of the bones of the *Elephas primigenius* buried in the white ore of the Dolores cave, establishes beyond doubt that a part, if not the whole, of the white ore is post-tertiary. If our view of the relations of that ore with the Smithsonite be correct, a part, if not the whole, of the latter must also be post-tertiary. This amounts to saying that all the chemical changes which the sulphides have undergone have occurred since the close of the tertiary epoch; and the existence of inundation mud in the joints and mineralized fissures, which would have been introduced since the commencement of the formation of the present river valleys, supports this view.

Suppose our hypothesis, that the zinc, at least, was originally precipitated as a carbonate, to be correct, at what epoch did this take place, and when was it partially sulphurized? As the metals occupy joints and fissures produced by dislocation, which were afterwards widened out by the solvent action of water, the deposition could only have commenced after the formation of the joints. Now, as the elevation of the Iberian Peninsula took place during the tertiary epoch, we may consider that the majority of the dislocations date from that epoch. We have already shown that the mines of the valley of Comillas actually occupy a fissure produced by an upheaval or subsidence which cannot be older than the eocene period, and may be of any age since, even post-tertiary. It seems probable, therefore, that the original precipitation of the zinc, and consequently of the lead, commenced not earlier than the tertiary epoch, and that most, if not

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derniers étant compris entre les couches que je viens de mentionner, on a donc des points de repère certains pour reconnaître leur horizon géologique.

" L'interruption fréquente de la couche calaminaire, son inclinaison variée et quelquefois très-forte, son aspect contourné, brisé et démantelé, son existence à différents niveaux, ses renflements et ses amincissements, sa teneur plus ou moins grande en minerai et divers autres accidents présentent, de prime abord, à l'œil peu exercé, des dispositions telles, qu'au lieu de concevoir une série de dépôts appartenant à une même couche, on y avait vu tantôt des amas irréguliers, tantôt des veines, des filons, etc., n'offrant aucune relation entre eux. Or, rien n'est mieux caractérisé, et j'ajouterai plus constant, plus régulier, que l'ensemble de ces dépôts calaminaires, si l'on a soin de les relier et de les rétablir dans leur allure et dans leurs positions primitives. C'est faute d'avoir procédé ainsi et c'est parce qu'on les avait considérés isolément qu'on n'avait pu reconnaître leurs caractères généraux, leurs rapports, leur véritable niveau géologique et leur mode de formation.

" L'existence des dépôts calaminaires de la province de Santander au milieu de couches des terrains crétacés et leur absence dans les autres terrains portent à admettre que leur formation a dû être contemporaine de celle d'une partie des terrains crétacés, et que la cause première du transport de leurs matériaux pourrait être attribuée à l'une des dislocations qui ont produit le relief des Pyrénées".

all, the transformations which they have undergone belong to pleiocene or post-tertiary times.

The thermal springs are, perhaps, connected with this series of upheavals, and the singular increase of temperature which took place in 1775 in the springs of Bagnères de Luchon, in the French Pyrenees, after the earthquake of Lisbon, shows that even still the dynamic power, which lifted up the whole peninsula, acts over as wide an area as ever. Those thermal springs must have begun their action near the coast only towards the close of the tertiary epoch. It may be objected, that as the sulphurization of the carbonates has apparently proceeded from above downwards, and not from below upwards, that it could not be effected by ascending thermal springs. It is not in the direct channel of a hot spring that we are to seek for the chief results of its metamorphosing action, but in the joints and fissures in the neighbourhood, into which the ascending water leaks and drains away. When M. Dufrenoy determined the discharge of water of the spring called Grande Grille, at Vichy, in 1852, its temperature was only 33° Cent., and its discharge 8,500 litres per twenty-four hours; while in 1854, after the removal of a fungoid growth of Arragonite by M. François, the temperature rose to 42°, what it was in 1775, and its discharge to 96,320 litres. What became of all this water, loaded with salts of lime, iron, and alkaline carbonates, while the channel was blocked up? It must have filtered away through joints and along the planes of bedding, altering everything in its course. If this were a sulphurous water, and that there were any deposits of oxides or carbonates in the neighbourhood, we would have phenomena of partial metamorphosis into sulphides perfectly analogous to what we have described in the Spanish mines.

Although much remains to be done yet to complete the study of those ores, we think we have produced evidence enough to establish the leading features of their mode of production and the extreme limits of their geological age. In the latter respect they present, so far as we know, the only case which has yet been established of the formation on a large scale of metallic ores in post-tertiary times.

[ADDENDUM.—We forgot to mention in the proper place two other instances of the connection between streams of water and metalliferous lodes, and consequently of the relation between alluvial mud and Halloysites. One of these is the remarkable cave of Dolores (p. 66), in which we have complete evidence that the mass of ore was produced by a stream. The other is the natural shaft in which a stream had evidently been engulphed, and which appears to be a continuation of the lode at Ruyloba (p. 63). We wish also to direct the reader's attention to the evidence afforded by the valley of Novales of the connection between the alluvions in the bottoms of valleys and the clays of lodes (p. 61). Another point deserving of attention is the relation between the transverse valleys, that is, the direction of the streams of water, and the mineralized points at Comillas (p. 57). And, lastly, it is worthy of note, in connection with the formation of blende, that wherever that mineral is found interspersed in the dolomite, the latter was black—that is, contained bitumen.]

ON THE

DEPOSIT OF SULPHATE OF SODA

OF THE

VALLEY OF THE JARAMA.

DEPOSIT OF SULPHATE OF SODA,

ETC.

ONE of the most characteristic physical features of Spain is the existence of extensive plateaus, or *parameras*, lying between high chains of mountains, and forming parts of the basins of the great rivers Ebro, Duero, Tagus, and Guadiana. Those plains consist chiefly of lacustrine beds, usually referred to the Miocene period; but the limestone of Vueltas de Segura in the central plain appears, according to M.M. De Verneuil and De Loriere,[1] to be of the same age as the freshwater deposits of the basin of Aix in Provence, which most geologists look upon as Eocene. Don J. Ezquerra del Bayo[2] states, that he knows of no marine tertiaries in the interior of Spain except in the neighbourhood of Burgos, which must have been a salt lake. The greater part of the basin of the Ebro, in which these marine beds occur, is occupied by argillaceous and calcareous beds full of *Planorbis* and *Limnœa*. This shows that the existence of freshwater lacustrine beds in a river basin does not necessarily imply that all the beds must be of the same character. Similar beds, containing the same organic remains, with the addition of *Paludina*, occur in the Duero basin. But while only traces of salt occur in the basin of the Duero, it abounds on the contrary in that of the Tagus, with which we are more immediately concerned.

The basin of the Upper Tagus is placed exactly in the centre of Spain, the great plateau which occupies its centre being from 2,000 to 2,500 feet above the sea. On the north the Somo Sierra and Guadarrama ranges, which commence on the frontiers of Aragon, separate Old from New Castile, and under the names Sierra del Pico, Montaña de Gredos, and Sierra de Gata, extend towards Portugal and divide the basin of the Tagus from that of the Duero. Another chain of mountains whose general direction is from west-south-west to east-north-east, consists of the ranges known as the Montes de Consuegra, Sierra de Yevenes, Montañas de Toledo, Sierra de Guadalupe, and divides the Tagus basin from that of the Guadiana.

Those mountains consist of granitic rocks of various kinds, and apparently of different ages, associated with gneiss, mica schiste, and the older palæozoic rocks; and in the Guadarrama and Somo Sierra ranges at least, with Devonian and carboniferous rocks also. On the flanks of the northern dividing chain rest cretaceous beds, often constituting large tracts of country elevated to a considerable height above the sea, such as the table land of Algora, in the province of Guadalaxara, on the high road from Madrid to Zaragossa, which is 1,160 metres above the sea, and composed of beds, the upper part of which is believed to correspond to the white chalk of northern Europe. Sometimes the cretaceous beds thus lifted up are horizontal; occasionally they are more or less inclined, and sometimes even almost vertical. The great plateau itself is occupied, as has been already indicated, by lacustrine tertiary beds, consisting essentially of compact limestone, gypsum, and marls, which often attain considerable thickness, especially in the plateaus south of Madrid on the road to Andalusia, and on the Cuesta de la Reyna, not far from Aranjuez.

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[1] Bullet. de la Soc. Géologique, t. xi. p. 661, etc.; noticed in Leonhard u. Bronn Neues Jahrb., 1835, p. 357.

[2] Journ. Geol. Soc. of London, vol. 6, 1850, p. 406.

The general physical character of this tertiary region is that of vast plains intersected by low ranges of hills and undulations, the beds being generally horizontal, and the contours, therefore, generally the result of denudation and the slow erosion of river valleys. According to Don Casiano de Prado,[3] the succession of the beds in a descending order is: limestone, clay (and gypsum), marl, sandstone, sand. M.M. de Verneuil and De Lorière[4] state that the tertiary rocks of central Spain almost always begin with thick conglomerates, consisting of large fragments of chalk limestone, apparently broken off by flowing water from steep escarpments, and carried short distances by cascades. They also mention the important fact that rich springs, cold and warm, like those of Deza and Alhama, frequently arise at the junction of this conglomerate with the chalk.

The limestone, or rather dolomite, which constitutes the upper member of the series, is very silicious, the corresponding rock in the Duero basin having exactly the same character. Fossils are often found abundantly in this tertiary limestone: thus at Trijueque, near Guadalaxara, it often appears completely full of *Limnæa*, *Planorbis*, *Paludina*, *Helix*, etc. Don C. de Prado also mentions the occurrence of bones of *Anoplotherium*, *Palæotherium*, *Antilope*, *Cervus*, *Sus*, *Rhinoceros*, *Hippopotamus*, *Mastodon*, etc., in the tertiary beds of the province of Madrid.[5]

In connection with the tertiary formations of central Spain

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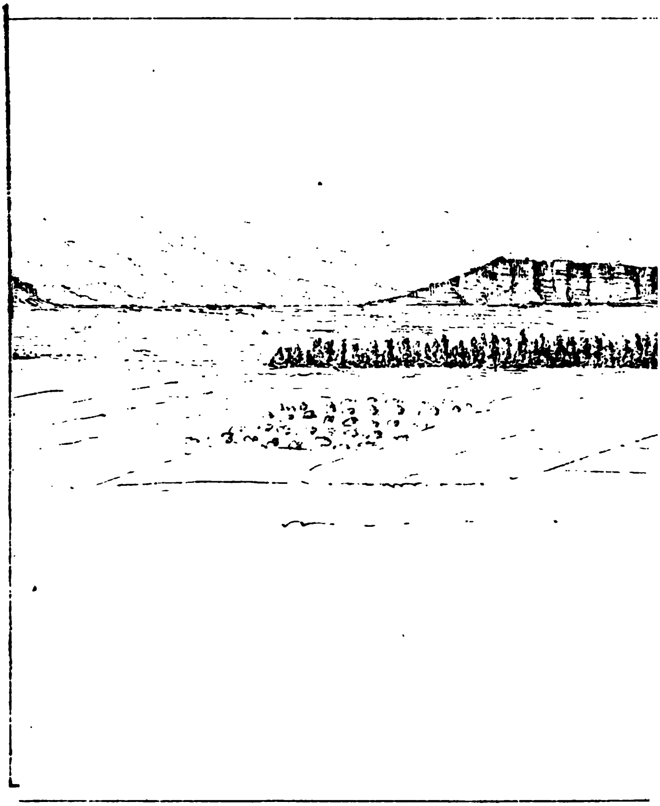
[3] Bullet. Géolog., t. x. 168, etc.; Leonh. u. Bronn. Jahrb. 1854, p. 845.

[4] Bullet. Géolog., t. xi. 661; Leonh. u. Bronn. Jahrb. 1855, p. 357.

[5] At page 169 will be found a short notice on the chemical composition of this dolomite, and the probable connection between it and the meerschaum of Vallecas, etc.



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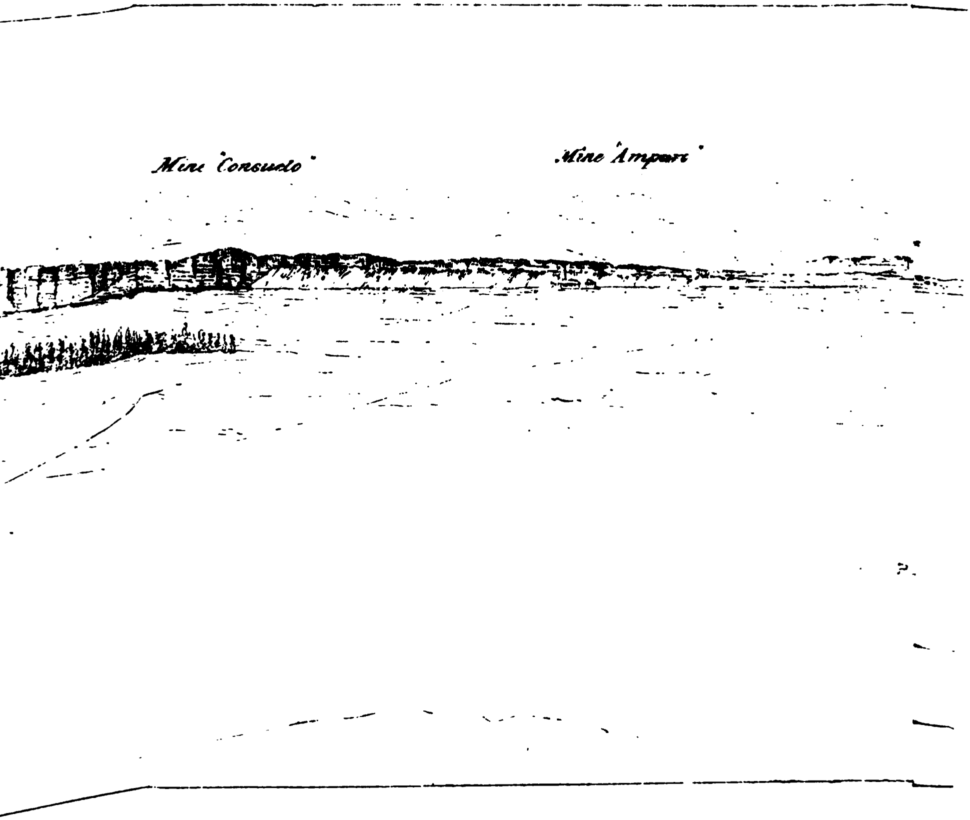
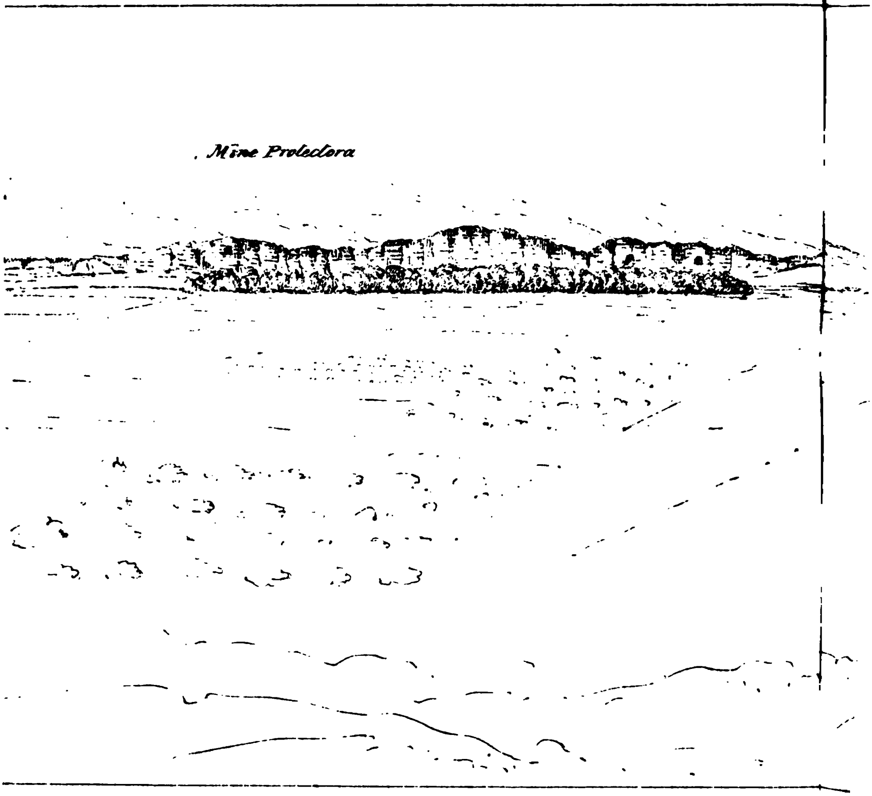


E VALLEY OF THE R. JARAMA



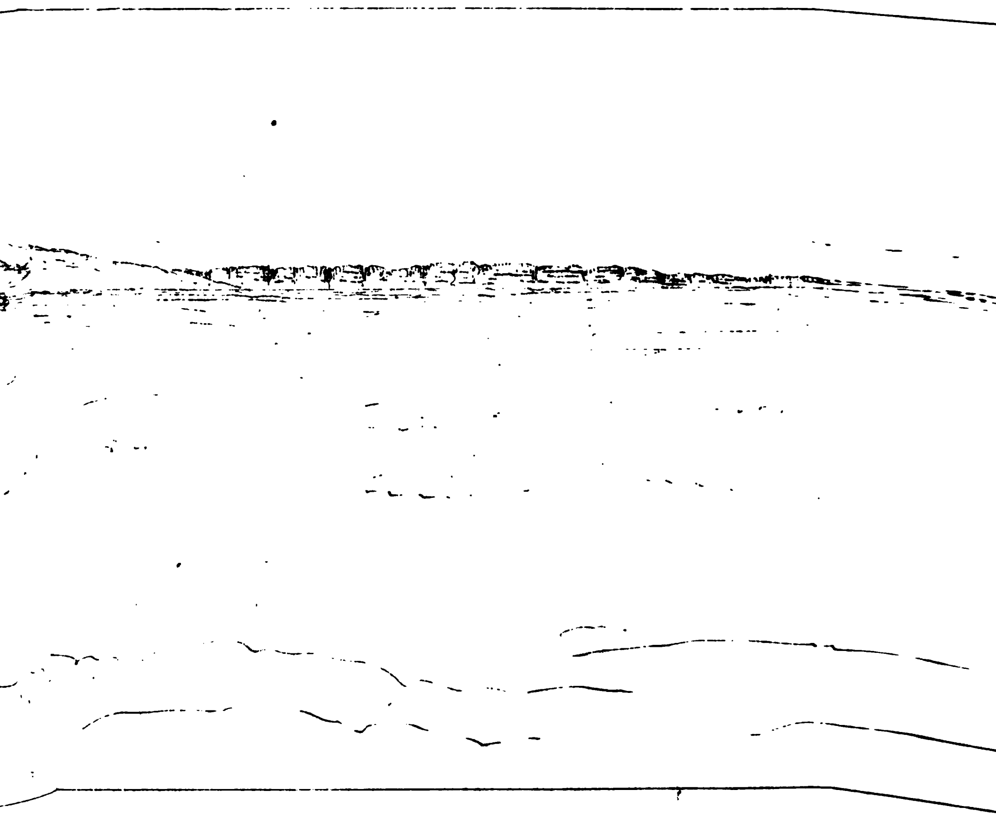


Plate No. 2.

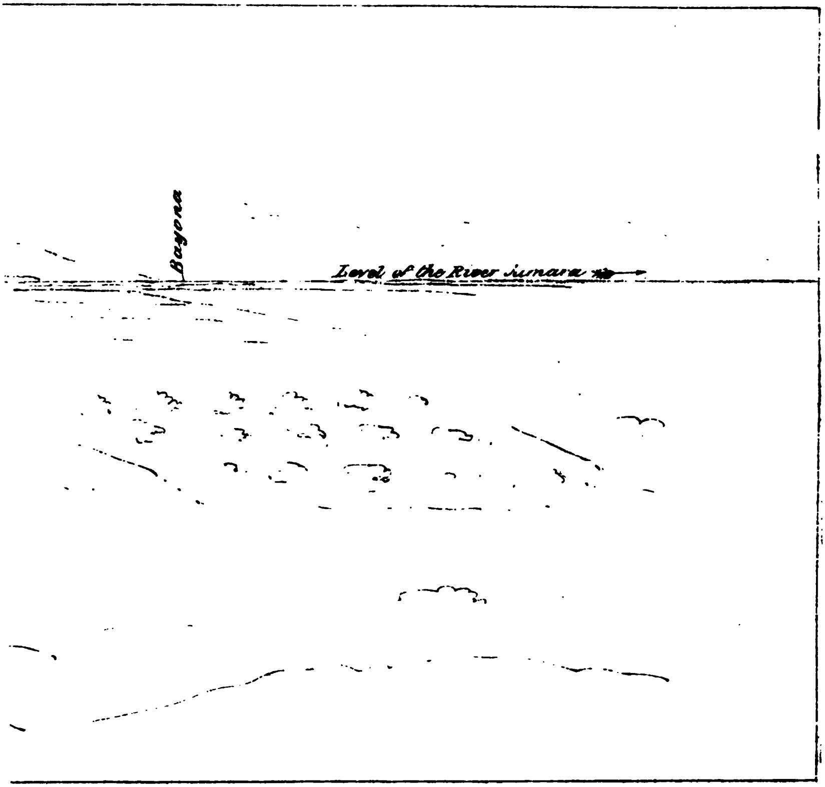
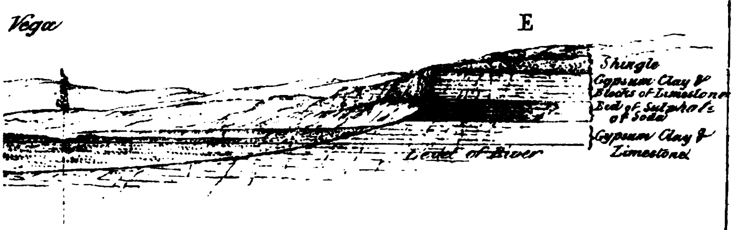
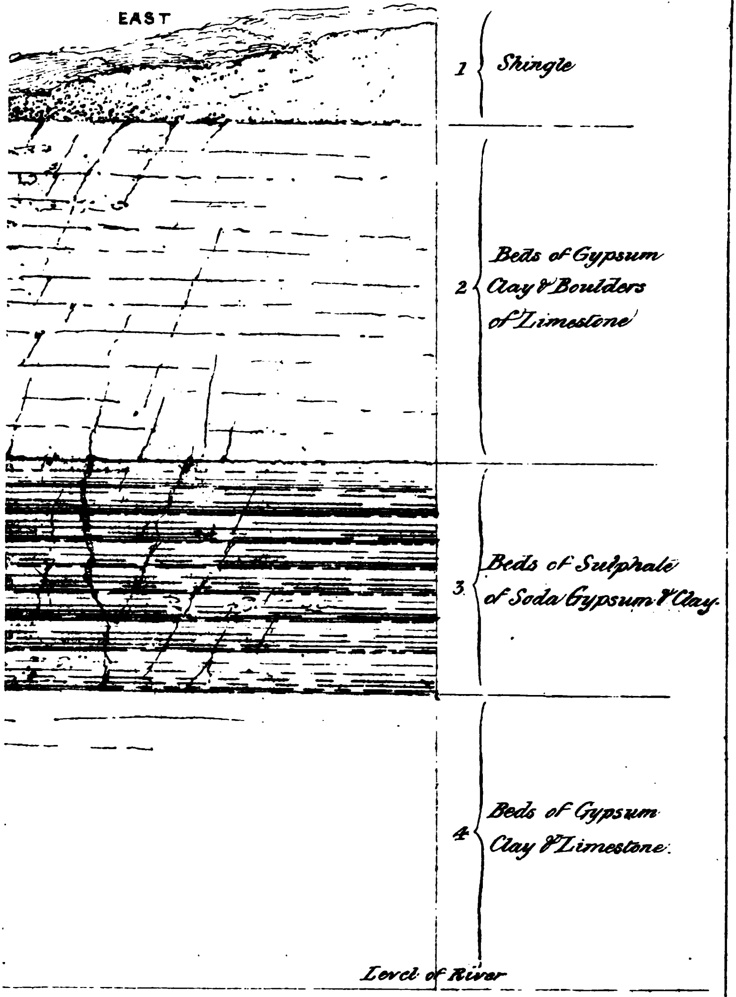

Bayona
Level of the River Jumara

Plate No. 3


Vega
E
Shingle
Gypsum Clay & Blocks of Limestone
Bed of Sulphate of Soda
Gypsum Clay & Limestone
Level of River


EAST
1 Shingle
2 Beds of Gypsum Clay & Boulders of Limestone
3 Beds of Sulphate of Soda Gypsum & Clay.
4 Beds of Gypsum Clay & Limestone.
Level of River

are found some very remarkable deposits of sulphate of soda, such as those of Lodosa, on the borders of Navarre and Old Castile, in the basin of the Ebro, of Calatayud, which is a detached lacustrine basin, and which is long known for the fine crystals of sulphate of magnesia which may be collected there, and that of the valley of the Jarama, near Aranjuez. These deposits are very curious and important as evidence of the character of past geological changes. So far as we know, no detailed description of any of them has yet been published. There appears to be some difference between the phenomena offered in the three localities mentioned, but apparently the most interesting deposit is that of the Jarama. Having had occasion to examine this last, we propose in the following pages to describe the circumstances under which it occurs, so far as our opportunities enabled us to study the district, and then to attempt to explain the origin and mode of deposition of the salt. The whole paper must be looked upon as a first sketch, because, as the reader will find, much remains to be yet done before the whole relations of this very curious deposit can be established. Indeed, in our opinion, it would be necessary to make a comparative study of the beds of Lodosa, Calatayud, and the Jarama, and of any others which are known, before this could be thoroughly done.

The centre of the province of Madrid, which is chiefly occupied by the tertiary and newer beds of the basin of the Tagus above described, is watered by the Jarama, a confluent of the Tagus which rises in the Guadarrama, passes by Guadalaxara, receives the Manzanares, a torrential river which traverses Madrid, and some other streams of less importance, and pours itself into the Tagus near Aranjuez (see the annexed outline map, "Valley of the Jarama, P$^{\text{ce.}}$ of Madrid", Pl. No. 1). Between the latter place to the south, and the village of Arganda to the north, extends a beautiful valley or vega of great fertility, watered by the Jarama, and bordered here and there by hills of slight elevation, sloping gently to the Vega on the west, but rising abruptly on the eastern side, and presenting escarpments, intersected by narrow valleys all along the river from Arganda to Bayonna, a small village four miles to the north of Aranjuez. Plate No. 2 represents a general view of these escarpments along the whole eastern side of the valley between the points mentioned, the foreground representing the vega. Plate No. 3 shows a section across the valley indicating the general character of the east and west sides. In the same plate there is also an enlarged section of the eastern bank of the river showing the escarpment along that side.

It is along the eastern side of this valley that the deposit of sulphate of soda is found. The extent of the principal line along which it occurs may be estimated at from 13 to 15 miles, but the richest beds are found in the neighbourhood of San Martin de la Vega, a village situated on the alluvial plain north-east of the river, and about 12 to 13 miles north of Aranjuez (see Plate 2).

The valley between the points indicated is sometimes covered by the inundations of the Jarama when it becomes suddenly swollen; this circumstance has led to its being represented as a lake upon several maps. These inundations, due as much to heavy rainfalls as to the melting of the snow of the Guadarrama, are very frequent in winter, and rise rapidly, reaching sometimes in one night a height of $1^{m}\cdot50$ to $2^{m}\cdot0$ above the ordinary level of the river. The Jarama having been cutting its bed gradually deeper and deeper, the extent, power, and frequency of these inundations have been diminishing, even in the memory of the present inhabitants. Along the western side, at some distance from the river, are found the ancient banks at a height above the actual plain of $4^{m}\cdot5$ to $5^{m}\cdot0$. The bottom of the alluvial plain is composed of rolled gravel, or rather shingle, consisting of quartz and quartz conglomerate, very much like the Old Red Conglomerate, pebbles and large stones of granite, and porphyritic syenite, from the Guadarrama. On this have been deposited successive layers of alluvial mud, brought down by the inundations of the river, and which constitute the rich arable soil of the vega.

The bottom of the river valley, upon which the quartzose and granitic shingle has been deposited, is composed of gypsum mingled with lumps of the white silicious limestone above mentioned, and of a grayish green highly plastic clay, called locally "greda". This rock appears to constitute the floor of a considerable portion of the province, and from its soft and yielding nature is easily eroded by rivers. The Jarama has cut through a considerable thickness of it, producing the escarpments along the eastern side. The bank of sulphate of soda is intercalated in this deposit of clay and gypsum, and crops out where not covered by a talus of clay about midway between the vega and the top of the escarpment.

Plate 2 shows an enlarged section of the escarpment on the eastern side of the alluvial plain at a point 1½ miles north of the village of San Martin de la Vega. The lower portion of the section represents the beds of gypsum, *greda*, and lumps of white silicious limestone. Upon these rest a succession of thin beds of sulphate of soda, gypsum, and *greda;* above these come beds of gypsum, *greda*, and lumps of limestone, similar to those upon which the sulphate of soda rests. These beds are covered by shingle similar to that filling the trough of the valley, and above all comes the soil.

The position of the shingle shows clearly that the Jarama has gradually eroded the whole of the Vega valley out of these beds since the deposition of the shingle; the part of the latter which once formed a continuous layer from the top of the escarpments of the eastern side to the western one, being now in the trough of the valley where they dropped as they toppled over according as the water washed away the clay and sulphates beneath them.

The bank of mineral has a variable thickness of from 16$^{m.}$ to 17$^{m.}$; in some places borings indicated a thickness of 19$^{m.}$, which there is reason to believe is a maximum thickness. Its horizontal extension or breadth towards the east does not appear to be very considerable, judging from the fact of the gradual disappearance of the sulphate of soda, and its replacement by clay, which was established by a level or gallery actively driven in that direction in the mine "El Consuelo". This would seem to prove that the deposit forms a lenticular mass, such as would have been deposited in a lake. It is indeed probable that a lake anciently existed here, the outlines of which will be indicated by those of the sulphate of soda. If the present vega occupies the middle of the ancient lake, sulphate of soda may also be found on the western side, where the beds exactly correspond with those on the eastern one, the outcrop of the beds being concealed by the sloping talus of gravel and clay. The river may, however, have begun the erosion of its bed more towards the western margin of the filled-up lake, and then cut back eastwards according as the soluble sulphate was washed away, forming escarped banks only along that side, but forming a sloping talus upon the opposite one. If this were so, no sulphate of soda would now exist upon the western side. When the river was at the level of the soda beds, the erosion of the valley must have been very rapid, and the water of the Jarama as it poured into the Tagus must have been highly charged with sulphate of soda. Even still, some sulphate of soda, dissolved by the rain water falling upon the cliffs, must drain into the river. Perhaps an observation of Bowles may find an explanation in this circumstance. He stated that the water of the Tagus, which at Aranjuez is very bad, begins to become good again at Toledo. It is true that the Jarama enters the Tagus below Aranjuez, and could not, therefore, contribute to render the water impure at that place. It is probable, however, that the deposit of sulphate of soda in the valley of the Jarama is not an isolated instance in the district, but that similar deposits may exist in the course of the upper Tagus itself.

But whether the sulphate of soda of the Jarama has anything to do with the circumstance noticed by Bowles, there can be no doubt that it indirectly increases, if it does not wholly produce, the fevers of the Vega. In the first place, the drainage of Madrid is brought into the Jarama, where its putrefaction must be greatly favoured by the presence of sulphate of soda. In the second place, the soil of the Vega is more or less impregnated by sulphates of soda and lime, and when gradually drying down after having been inundated, we have all the elements necessary to develop intermittent and typhoid fevers, as the experience of the Etang de Lindre Basse, in the department of La Meurthe, has fully shown.[6]

The sulphate of soda exists in these beds in three states: 1. as anhydrous sulphate or Thenardite; 2. as hydrated sulphate, Exanthalose or glauber salt; and 3. in combination with sulphate of lime as glauberite. The chief mass consists of the anhydrous sulphate enclosing small irregular lumps of white saccharoidal gypsum and hard lumps of what may be called glauberite. The whole is mixed up with the greenish plastic clay, which we have already mentioned as *greda*, and is very regularly bedded as the section in Pl. 3 shows. The beds divide themselves into groups, each of which seems to be separated from the one beneath by a layer of the *greda*. The layers of salt of each group appear to increase in thickness in ascending, while the clay appears to increase in descending: in other words there is more clay in the lower part of each group of layers than in the upper. The uniformity of structure and regularity with which the groups of layers succeed each other, show that the production and deposition of the sulphate of soda were phenomena periodically recurring during long periods of time.

The mass of sulphate is so hard, that it is extracted by driving adit levels into the beds, which are worked by blasting with powder, and then by the pick. When freshly extracted the rock is massive, of a very dark colour, and breaks into very irregular masses, which exhibit numerous planes of cleavage as if made up as a mass of compressed crystals. Sometimes pieces almost free from clay are met with; they are, when freshly broken, highly translucent in large masses, and subtransparent, indeed in some cases transparent, in small pieces. When the irregular fractures are examined, they are found to consist of three distinct cleavage planes, two of them of inferior, but somewhat unequal, lustre, and which appear to be prismatic, and a third basal, which has the lustre, and frequently the iridescence presented by the principal cleavage of laminated gypsum. It may be readily split with a knife along this plane, but not with the same facility as gypsum, nor into such thin plates. The figure of cleavage is a right rhomboidal prism, which appears to have the same angular elements as M. Cordier found for the Thenardite of Espartinas. The lustre of the cleavage plane is rapidly dulled on exposure to the air, and almost instantaneously if breathed upon.. When pieces are left exposed to the air for some time, they become covered with a white powder like flour, which can be brushed off. The fracture of the large clear pieces, the natural cracks which generally run through them, and the phenomena which they present when light is transmitted through them, clearly show that they are made up of an agglomeration of distinct crystals, about the size of those usually found making up the mass of commercial glauber salt. These crystals are pressed together, and cemented into a solid mass by a paste of the salt itself.

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[6] M. Ancelon, Mémoire sur les fièvres typhoïdes periodiquement développée. par les emanations de l'etang de Lindre-Basse. Lu a l'Institut le 15 Mars, 1847 Nancy, 1847.

The dark colour of the principal mass is due to the intermixture of the grayish green clay or *greda*, which appears to be disseminated through the cementing paste, and also within the crystals themselves. This shows that the water in which the crystals were deposited was itself muddy, and that the mud did not come in periodically only, and gradually filter down between the bed of crystals before they became cemented. In some of the clear pieces of anhydrous sulphate, portions tinged of a beautiful amethystine colour were observed, the colouring matter appearing to be organic, perhaps due to a similar cause to that which gives rise to the blood-red colour in the brine of salt gardens.

When a mass of the anhydrous sulphate is moistened and exposed to the air, it rapidly absorbs the water, swells up like slacked lime; and this action continues until it is completely saturated. In the latter state it appears as a lump, of a snow white colour, having no appearance of crystallization, but readily crushing into a white meal. When treated with water, especially at a temperature of from 20° to 33° Cent., it readily dissolves, leaving the intermixed *greda* partly in suspension in the solution, and from which it is only slowly precipitated, especially if the solution be strong. During the dissolution of the mineral to extract the sulphate of soda, the sulphate of lime, and what we have called glauberite, separate also. The latter consist of hard gray balls, intermixed with clay, which do not appear to dissolve in water, but which, nevertheless, are distinguishable from the lumps of gypsum by the alabaster whiteness of the latter, and by the gray lumps becoming gradually coated with a crust of sulphate of lime.

Like all other beds of rock of whatsoever kind, those of anhydrous sulphate of soda became jointed by pressure and contraction along different planes. These cracks admitted water which first hydrated the walls of the cracks; and as the hydrated salt occupies a much larger volume than the anhydrous one, the cracks were generally gradually sealed up by glauber salt. The outcrops of the beds along the escarpment of the valley became gradually hydrated, and a part dissolved, and is carried away into the valley by the rain; but a considerable quantity has accumulated as a kind of talus, which becomes covered with clay and debris from the falling of the cliffs above, as is shown in the enlarged section of the eastern bank of the river valley, Plate 3. This hydrated sulphate of soda, or natural glauber salt, the Exanthalose of Beudant, and the mirabilite of other mineralogists, consists of an agglomeration of small crystals about the size of coarse grained lump sugar, cemented into a compact more or less saccharoidal mass. When free from clay these small crystals are beautifully transparent. When a lump is broken by a smart blow, it sometimes exhibits a vitreous fracture, not unlike some kinds of quartz; generally, however, the mass easily crushes into the separate crystals of which it is made up. The less pure parts contain clay and sulphate of lime intermixed with the crystals.

The specific gravity of the Thenardite was found to be 2·741, and that of the hydrated salt 1·4492 at 12°2 Cent.

The following table contains the result of the analysis of the Thenardite:

	a	*b*			
NaO . .	42·902			NaO,SO_3 . .	98·302
KO . .	0·148			KO,SO_3 . .	0·273
CaO . .	trace			MgO,SO_3 . .	1·349
MgO . .	0·459		=	CaO,SO_3 . .	traces
MgCl . .	0·010	. . 0·023		MgCl . .	0·010
SO_3 . .	56·502				
	100·021				99·934

The specimen *a* was perfectly transparent, and had all the surfaces of the crystal removed by cleavage. The specimen *b* consisted of a fragment of the mass, including several crystals, or parts of crystals, and shows very clearly that more chloride of magnesium is to be found along the planes of contact than in the mass of the crystal, and that consequently the mother liquor from which the Thenardite had separated must have contained some magnesian salts, and especially chloride of magnesium.

An extremely pure specimen of the hydrated sulphate of soda was found to have the following composition:

$$\left.\begin{array}{lr} NaO & 19{\cdot}047 \\ CaO & 0{\cdot}004 \\ MgO & 0{\cdot}068 \\ SO_3 & 24{\cdot}598 \\ HCl & \text{minute traces} \\ HO & 55{\cdot}770 \\ \hline & 99{\cdot}487 \end{array}\right\} = \begin{array}{lr} NaO,SO_3,10HO & 98{\cdot}9900 \\ CaO,SO_3,\ 2HO & 0{\cdot}0137 \\ MgO,SO_3,\ 7HO & 0{\cdot}4233 \\ \hline & 99{\cdot}4270 \end{array}$$

Although the specimens of both minerals analysed represent the purest portions of the mass, their results do not differ very much from what we should obtain from an average specimen of either. We may consequently look upon both as exceedingly pure minerals—purer, indeed, than the majority of specimens of commercial glauber salt.

The problem of how this remarkable deposit of sulphate of soda was formed, does not necessarily involve that of the source of the sulphuric acid itself, and which, in combination with lime also, is so extremely abundant in the whole central plateau; for whether that acid came up from some volcanic centre, or other subterranean laboratory, in a free state, as it does in the water of the Rio Vinagre, which issues from the volcano of Purau in the Andes, and in that of the abundant spring discovered by M. Degenhart, which issues from the Paramo de Ruiz, at an elevation of 12,000 feet, in the same chain, and in the less important springs of Cransac in the south of France, or even as an alkaline sulphate, as in the waters of Aix la Chapelle and other saline springs, it would be gradually brought into combination with lime or magnesia in its passage over rocks, and through soils, abounding with both earths. Even the sulphates of iron and of alumina, produced by the slow oxidation of pyrites or other metallic sulphides, are very soon transformed into sulphates of lime and of magnesia. Whenever, then, we find in nature large masses of sulphate of soda, either forming a bed in sedimentary rocks, or dissolved in the water of lakes, we may assume, unless under very exceptional conditions, that it was produced by the action of chloride of sodium upon sulphate of magnesia or sulphate of lime, or upon both together.

Starting then from this hypothesis, let us first examine under what conditions sulphate of soda can be formed by the action of common salt upon the sulphates of the alkaline earths; and in the next place, whether any such conditions exist naturally as would produce large masses of that substance.

Sulphate of soda may be produced from sulphate of lime, or magnesia, by the action of common salt upon them, under two conditions:—1. At warm temperatures; and 2. at temperatures below the freezing point. We shall discuss the subject in this order.

When a solution of salt containing sulphate of lime is evaporated to dryness at a boiling temperature, a partial decomposition takes place, and some sulphate of soda is formed, as Döbereiner showed. This decomposition is never complete, no matter in what proportion the original salts may be present; neither does any at all appear to take place during the slow evaporation of such a mixed solution, even at a temperature of 40° Cent.

When solutions of chloride of sodium and sulphate of magnesia are mixed together, and evaporated at temperatures above 50° Cent., anhydrous sulphate of soda, and chloride of magnesium, are formed, according to Heinrich Rose. At common temperatures no decomposition appears to takes place, at least no sulphate of soda is obtained when the solution is fully evaporated. Indeed, so far from sulphate of magnesia and chloride of sodium mutually decomposing each other at ordinary summer temperatures, the inverse change takes place with such facility between 40° and 50°, that sulphate of magnesia is frequently made in this way on a large scale by adding glauber salt to the mother liquors of salt works rich in chloride of magnesium. The reactions of sulphate of magnesia and chloride of sodium on the one hand, and of sulphate of soda and chloride of magnesium on the other, depend chiefly on three circumstances—temperature, degree of concentration of the solution, and relative proportions of the mixed salts. Sulphate of soda and sulphate of magnesia have equal solubilities at two temperatures, 30° and 48°; between both lies the point of maximum solubility of the former, at a little above 33°. Below 30° the solubility of the sulphate of soda sinks so rapidly, that at 24° it is about the same as that of sulphate of magnesia at 0°. Hence, at temperatures below 30° there is a tendency to form sulphate of soda, if equivalent quantities of saturated solutions of chloride of sodium and of sulphate of magnesia be mixed, as we shall see hereafter. Between 30° and 48° the converse is the case, that is, sulphate of soda and chloride of magnesium will tend to decompose each other, and produce sulphate of magnesia and chloride of sodium. Above 48° the character of the reaction is again reversed, and is not again altered at any higher temperature at which the experiment has been tried. It is only, then, at temperatures above 48° or 50° that crystals of sulphate of soda are precipitated from brine containing sulphate of magnesia.

The sulphate of soda, which forms so considerable a constituent of all scums, and panstones or "scales" formed during the evaporation of the brine of salt springs,[7] appears to originate in a decomposition of the kind just described. The following table shows the composition of three such scums, and of the corresponding "scales" according to the analyses of M. Heine.[8]

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[7] Sulphate of soda, uncombined with other sulphates, or as glauberite, that is, a double sulphate of lime and soda, is, no doubt, a constant constituent of the incrustations formed on the bottoms of marine boilers.

	SCUM.			SCALE.			
				I.		II.	III.
	I.	II.	III.	a.	b		
CaO,SO_3 . .	23·649	50·773	29·904	27·381	45·779	71·941	20·198
NaO,SO_3 . .	13·499	6·856	28·942	20·667	40·407	7·452	20·925
KO,SO_3 . .	1·839	0·991	0·712	2·125	0·791	1·017	1·339
MgO,SO_3 . .	0·409	0·226	0·094	1·638	1·120	0·433	1·438
Na,Cl . .	57·102	82·951	82·060	44·284	10·566	10 771	53·426
MgO,CO_2 . .	0·567	0·385	0·058[9]	0·408	Trace	0·210	0·316
CaO,CO_2 . .	——	0·448	0·077	——	0 060	0·095	0·467
$Fe_2O_3+Al_2O_3$.	0·060	0·083	0·086	0·080	——	0·133	0·118
Si,O_2 . .	0·020	0·135	0·083	0·023	0·022	0·150	0·085
HO . . .	2·855	6·556	7·084	3·444	1·255	6·195	1·686

I. Scum of brine from No. 3 boring at Schönebeck; *a.* scale from boiling pan before clearing out; *b.* scale of salting pan.
II. Scum and scale of boiling pan from Dürrenberg.
III. Scum and scale from Kösen.

The scales I. and III. contain the sulphate of lime and soda in quantities approximating to the proportions in which these salts exist in glauberite; they are also present in the anhydrous condition. This circumstance is of considerable interest, as it shows that anhydrite can be formed at temperatures very little above 100° Cent.

By rapid evaporation at a boiling temperature the deposit or scale formed on the heated bottom of the pan would contain some of all the salts actually in solution at the moment in the brine. By slow evaporation, on the other hand, upon a uniformly heated bottom, and as in lakes less heated than the evaporating surface, the salts crystallizing out would be successively deposited; but sometimes a deposit would consist of two or more salts mixed, or in combination. This has been well shown by the beautiful researches of M. Balard.[10] He found that when sea water was evaporated until its density marked 7° of Beaume's areometer, oxide of iron and carbonate of lime began to be thrown down, the precipitation continuing until the areometer marked 14°. At 16° to 17° carbonate of lime and magnesia, dolomite in fact, was precipitated; from 20° to 25° pure crystallized fibrous sulphate of lime was exclusively thrown down. The deposit augmented greatly when a strength of 26° was attained, but it was now a mixture composed of chloride of sodium (95 per cent.), sulphate of lime, sulphate of magnesia, etc. At 30° the water contained no more sulphate of lime, and the deposit consisted of about 94 per cent. of chloride of sodium, and about 4 or 5 per cent. of different magnesian salts. Finally, at 35° the deposit consisted of a mixture of salts, of which chloride of sodium formed only 60 per cent., and sulphate of magnesia 18 per cent. In these experiments we have a confirmation of what has been above stated, namely, that at moderate temperatures there is no sulphate of soda obtained by the evaporation of brine containing sulphates of the alkaline earths.

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[8] Archiv für Mineral. u. Geog., xix. 3; Karsten—Lehrbuch der Salinenkunde ii.

[9] MgO, containing some chlorine.

[10] Etudes sur la composition de l'eau de la Mediterranée. Annal. de Chim. et de Phys., t. xxvii. 1849, p. 175.

Let us now study the nature of the reactions which take place in saline solutions containing chloride of sodium and sulphates of the alkaline earths, at temperatures below the freezing point.

If solutions of sulphate of magnesia and chloride of sodium be mixed, and exposed to temperatures below the freezing point, the two salts will decompose each other, and glauber salt and chloride of magnesium will be formed. In like manner, sulphate of lime and chloride of sodium will produce chloride of calcium and sulphate of soda, as was first noticed by Hahnemann. If powdered gypsum be put into a saturated solution of common salt, and exposed to a very low temperature, it will be decomposed, the extent to which the decomposition may proceed depending upon the duration of the low temperature, and its intensity. If an equivalent of each be mingled, and exposed for months to a very intense cold, the decomposition may even become complete. A piece of dry plaster of Paris, which from its great porosity, readily absorbs saline solutions, if plunged for some time into a strong solution of salt at a temperature considerably below the freezing point, will be decomposed, crystallized glauber salt will separate, and the solution will contain chloride of calcium. Fibrous gypsum exposed for a long time to the action of a very cold solution of common salt, is acted upon, although the action is necessarily very slow; while hard saccharoidal crystalline gypsum, which is very slowly penetrated by strong saline solution, is scarcely changed except upon the external surface.

Even alum (and also sulphate of alumina) yields glauber salt when a solution of it is mixed with one of common salt, and exposed to a temperature below 0° Cent.

Salt prepared in Siberia from brine, which during winter has been exposed to a very intense cold, is always found to contain glauber salt. Hess[11] found, for instance, in a sample of salt from

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[11] Bulletin de l'Academie de St. Petersbourg, T. vi.

Selinginsk, south of Lake Baikal, 13·8 per cent. of sulphate of soda, and in one from Ustkutzk in the Lena valley, 12·6 per cent. A better example still of this change is afforded by the result of the treatment of the mother liquors at the salt works of Moutiers. They are kept in reservoirs until winter; under the influence of the low temperature the sulphate of magnesia and chloride of sodium decompose each other, and form chloride of magnesium and sulphate of soda. Three deposits are successively formed, the last of which is nearly pure sulphate of soda—that is, more of the latter is thrown down the longer the duration of the action. The following table shows the character of the changes which take place:

	Mother liquor from the salt pan.	First deposit.	Second deposit.	Third deposit.	Final mother liquor.
NaO,SO_3	——	46·36	56·50	95·00	6·00
MgO,SO_3	9·50	11·74	0·25	——	4·20
NaCl	20·80	41·30	43·00	5·00	19·90
MgCl	4·85	0·60	0·25	——	5·40
Water,	64·85	——	——	——	64·50

It is to be observed of such analyses, that they are to be considered not as representing the actual composition of a consecutive series of products from one solution, but as the average composition of these salts and solutions as they are actually found in the tanks of a large salt works. The bromides and iodides are not stated. It is almost unnecessary to observe that the deposited sulphates are to be considered as hydrated.

We have now to see whether such decompositions, which can be effected not only on a small scale in a laboratory, but also in a large manufacturing one, take place as common operations of nature. The best field for the study of natural hallurgical operations must obviously be those regions which abound in salt, salt lakes, and saline efflorescences. The great Aralo-Caspian depression is, perhaps, the best example of such a region which we could select for our immediate purposes. This region contains numerous lakes, some of which have almost pure solutions of common salt, while others are bitter, and abound in sulphates, or in chloride of magnesium. Various kinds of saline efflorescences, and saline swamps likewise, occur throughout the region from the Volga to beyond the Aral Sea. Near the Kigatsch, or eastern arm of the river just mentioned, there exists a group of seventeen remarkable lakes, which are known as the Karrduan lakes, and one of which will serve as a type of all the others. According to Göbel,[13] 100 parts of the water of one of those lakes had the following composition:

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[13] Reise in die Steppen des südlichen Ruslands, 2 Bde. Dorpat, 1838. Bd. ii. S. 54.

$NaCl$	10·538
$MgCl$	9·912
MgO,SO_3	8·220
Water,	71·328
	99·998

During the winter a remarkable deposit about one foot thick of a salt, first noticed by Pallas, is formed in this and all the other Karrduan lakes. This salt, which has been called Astrakanite by G. Rose, crystallizes in transparent prisms, which effloresce in the air, and has, according to the analysis of H. Rose, the following composition:

NaO,SO_3	41·00
MgO,SO_3	35·18
$Mg,Cl.$.	0·33
CaO,SO_3 and Sand,	1·75
HO	21·56
	99.82

which corresponds to the formula $MgOSO_3,NaO,SO_3,4HO$. The corresponding artificial compound, like all the similar double salts of the magnesian sulphates, contains six equivalents of water. Perhaps the smaller quantity of water in the natural salt may be due to the action of the dense solution of chloride of magnesium. During the greatest cold of winter, glauber salt, uncombined with sulphate of magnesia, appears to be precipitated along with chloride of sodium in these lakes, forming the globular masses of compound salt which are found on their margins. A compound of hydrated chloride of sodium with glauber salt can, in fact, be formed in concentrated brines at very low temperatures in globular masses, composed of radiating prisms, which lose part of their water at temperatures approaching 0° Cent. These lakes have, accordingly, a summer and a winter composition; during the former period they contain very little (if any at all) sulphate of soda, while in winter there is a large production of the latter salt.

The marine tertiary formations which occupy the region between the Irgis and the Syr-Darya, or Jaxartes, and through which flows the Turgai, afford some examples of still more utility for our purposes. These formations consist chiefly of gypsum, loams, sand, brown coal beds, highly fossiliferous laminated clay marls, and sandstones. In journeying from the upper Irgis towards the Aral Sea, the land gradually falls towards the latter; this, together with the denudation of the surface and the erosion of valleys, brings a succession of beds to the surface, which M.

Nöschel, who has recently traversed those wild steppes,[13] classifies into three groups. The first, or uppermost, consists of a yellowish quartz sand, mixed with limestone, brown hæmatite, and fragments of shells; a yellowish red sandy loam; a loose yellowish quartz sand; bright brown saline, often fetid clay, and loose sand. This group of beds forms hilly sand wastes of variable extent, the hills sometimes rising to 100 feet, resting here and there upon what we may call the general steppe floor, and very frequently in caldron-like hollows in its surface. All the wells of fresh water in the region are found in this group. The second group includes what we have called the general steppe floor, or clayey and marshy soil which fills up the hollows and funnel-shaped depressions, which have been eroded out of the underlying beds composing the group. These beds consist of—1. Alternating layers of yellowish, gray, and reddish calcareous sandy clay, free from salt, and similar coloured salt loams, containing tertiary shells, gypsum,—sometimes in rhombic prisms, sometimes sparry, laminated, or fibrous,—and compact marly clay, and sandstone plates; and sometimes also boulders and gravel of crystalline rocks. The salts which are found in the loams are almost exclusively sulphates, such as sulphates of magnesia, protoxide of iron, and soda. The quantity of sulphate of magnesia is often so great that woolly filamentous efflorescences of it cover the clay in the dry weather in lichen like patches an inch thick. Common salt is only very sparingly found among those beds. 2. Yellowish gray, often passing into a dark coloured saline clay, which is often boggy, and evolves sulphide of hydrogen and marsh gas. In addition to the salts just mentioned, this clay abounds in common salt, and consequently salt lakes and salt swamps are formed where it crops out. The chloride of sodium appears here as hard, compact layers, composed of large cubical crystals, sometimes an inch in the side, filling the bottom of the lake; upon this rests the mother liquor, or when nearly the whole of the water has evaporated, a stinking, dark gray saline loam, upon which a vesicular crust of sulphates and other salts rests. Brown coal, pyrites, sulphur mud, alum, and debris of gypsum also occur here and there in this group.

The third group of beds, inferior to those mentioned, consists of the following series:—1. A spongy, hygroscopic, yellowish saline clay, often full of marly clay plates and flint-like silicious gravel, which forms the tops of the elevated country. 2. Yellowish gray marly loam, containing loose gypsum pieces, white veins of quartz sand, and layers of the flint-like silicious gravel, and abounding in glauber salt. Wherever this bed crops out, lakes, containing a solution of glauber salt, are formed; such, for instance, as the one which occurs about forty wersts north of Raim Kale, on the Aral Sea. 3. Gray slaty clay marl, with intercalated layers of crystalline gypsum, an inch thick, and of grayish, green, argillaceous sandstone. 4. A soft, sandy, and often also salty, grayish yellow loam, traversed by veins of yellowish, coarse, loose, sand veins, which forms the bed of the Syr-Darya to the Sea of Aral. According to Von Helmersen, the shells which are found in the grayish green sandstone No. 3, appear to be all eocene.

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[13] Bemerkungen über die naturhistorishchen, insbesondere die geognostisch—hydrographischen Verhältnisse der Steppe zwischen den Flüssen Or und Turgai, Kumak und Syr-Darja Von A. Nöschel—mit einem Vorwort und Bemerkungen von G. von Helmersen—Beiträge zur Kentniss des russischen Reiches Bd. 16, St. Petersburg, 1856.

On the journey from Uralskoye to the Aral Sea, at Raim-Kale, M. Nöschel observed a number of lake-like accumulations of water, which were more or less salt and bitter, and even frequently became true, rich, common salt lakes, covered with a white salt crust. Sometimes the water was so muddy that it could be obtained clear only by passing it through a very thick filter. He states that, " this peculiar muddiness of the water was, in fact, a very remarkable phenomenon, as one should have expected that the mud in suspension in the water, would in time have deposited in the still lake, and have formed at most a mere deposit at the bottom. On the contrary, one always finds the water muddy, and the more the water diminishes by evaporation, the muddier it becomes; and, at last, when all the water is evaporated, the fine clay remains behind as a thin, smooth coating. Lakes of this kind, which almost always appeared to be formed of the rain water of spring only, for the most of them dried completely down during the summer, were found more on the northern end of the sand deposit, and imparted by their silver-like sheen, when seen from a distance, a peculiar but very depressing character to the landscape". Such annual or periodic lakes, generally rich in salts, are very common over the whole Kirghiz steppes, some of them being of considerable size, as, for example, the great salt lake of Tas-Kul. Many lakes appear to have become permanently dried up in the steppes, and some think that the water of the whole Aralo-Caspian depression is slowly diminishing.

We might find in South America also many similar examples of saline lakes and efflorescences, but one will suffice for our present purpose. Mr. Darwin was particularly struck with the efflorescences of Bahia Blanca, northward of the mouth of the river, or rather river-bed, of the Colorado. This efflorescence consists of glauber salt mixed with only very little common salt. The districts where glauber salt effloresces are called *salnitrales*, to distinguish them from the *salinas* where common salt occurs. As long as the ground is moist, one sees only a wide extended plain, consisting of a black, greasy soil, which nourishes scattered bushes and salt plants. In hot weather the soil is completely white, as if covered with flakes of snow (hence, no doubt, the name *Bahia Blanca*), which is due to the tendency of the salt to crystallize, like hoar frost, upon the stalks of grass.

Having thus shown that sulphate of soda can be readily produced by the action of common salt upon the sulphates of the alkaline earths, and that such changes take place on a large scale in nature, we shall now proceed to endeavour to apply those facts towards explaining the origin of the beds of sulphate of soda of the Jarama. In order to satisfactorily account for the origin of the beds in question, we have to take into consideration the following circumstances: 1. That the sulphate of soda appears to have been originally deposited in a lake-like depression, and is nevertheless nearly free from chlorides, especially of sodium; 2. that the salt must have been deposited from a solution in anhydrous crystals, and that the absence of combined water was not produced by any subsequent change; 3. that the water of the lake was shallow and muddy, and that the crystals were formed while it was in this muddy state; 4. that the production of the sulphate of soda was a regular periodic phenomenon, which took place apparently under conditions as to temperature, etc., almost absolutely the same as exist at present.

Whether the sulphate of soda of the valley of the Jarama was formed from the sulphates of magnesia and lime, by the action of common salt at temperatures above 50° Cent., or below 0°, it is evident that it was not formed where we now find it, that is, that the ancient lake was not an ordinary salt lake, or the mother liquor left after the deposition of some great bed of salt, for otherwise we should find beds of the other salts which occur in mother liquors and brines, or combinations of them with sulphate of soda, alternating with the beds of the latter salt. The constitution of the scum and scale formed at a boiling temperature, the deposits which take place during the evaporation of sea water at common temperatures, and the deposits formed in the Karrduan lakes at temperatures below the freezing point, all alike place this fact beyond doubt. Again, the salt must have been separated from its solution at a temperature above 35° Cent. Dr. Thomson long ago pointed out that when a solution of sulphate of soda is evaporated at a temperature of 40° anhydrous crystals are formed.

This result has been confirmed on a large scale by M. Balard, who found that, when sulphate of soda was deposited by the evaporation of the mother liquors of salt gardens in summer, it was anhydrous whenever the temperature exceeded 35°.

The deposition of the sulphate of soda of the valley of the Jarama in anhydrous crystals, which require for their formation a temperature above 35°, is in itself a very strong argument in favour of the opinion expressed above, that the sulphate of soda was not formed in its present site by the decomposition of the alkaline earths. We have seen above that sulphate of soda could only be precipitated from a brine containing sulphate of magnesia at temperatures above 48° or 50°. At this temperature the crystals would, of course, be anhydrous, but as the difference of solubility of sulphate of magnesia and sulphate of soda is not very great between 50° and 60°, the highest summer temperatures at which we could suppose the evaporation to have taken place, sulphate of magnesia would always be precipitated along with the sulphate of soda, inasmuch as the production of the latter salt, by the decomposition of the sulphate of magnesia, would not compensate for the evaporation of the water, which would always keep the solution at the maximum of saturation for sulphate of magnesia. Again, above 15°·5 sulphate of magnesia is more soluble than chloride of sodium, and above 28°, sulphate of soda is more soluble than the same salt, and as even in mother liquors of salt works, and such steppe lakes as may be looked upon as mother liquors, there is always more chloride of sodium than sulphates present, the point of saturation for chloride of sodium would consequently be reached before that for the sulphates mentioned, and it would consequently begin to be precipitated before, and along with, any sulphate of soda formed.

The exact temperature at which any particular change of constitution would take place in a solution of several salts, would, no doubt, be greatly influenced by the third circumstance which we have mentioned as exerting an influence upon the reactions of salts in solution (*ante*, p. 148). It is, however, unnecessary to enter into any details upon this very complicated point, if for no other reason than that we have no accurate data to depend upon. For our present purpose it is sufficient to state that the points of saturation for sulphates of magnesia and soda are only reached, in the case of sea water and the majority of the brines of springs, after a large part of the common salt has been precipitated, when the evaporation takes place at temperatures below 50°. But at higher temperatures, for example 90° to 110°, where the solubility of sulphate of soda approaches more and more that of chloride of sodium, as the composition of saline scums and panstones or "scales" shows, the point of saturation for sulphate of soda, or its combination with sulphate of lime-glauberite, may be reached almost at the same time as for common salt.

The higher the temperature above 48°, then, at which a brine or mother liquor may happen to be evaporated, the more sulphate of soda would be formed. Possibly the gray salt of Vic, in the department of La Meurthe, which occurs in the Jurassic formation, and which consists, according to M. Berthier, of 90·3 per cent. of chloride of sodium, 5·0 of anhydrous sulphate of lime, 2·0 of anhydrous sulphate of soda, 2·0 of anhydrous sulphate of magnesia, bituminous clay, and oxide of iron, and 0·7 of moisture, may have been formed at a temperature above 50°. The polyhalite of Vic, which is simply Glauberite, as well as the latter mineral found in other localities, such as Villa Rubia, near Ocaña, in the basin of the Tagus in Spain, Iquique, in the desert of Atacama, in South America, etc., seem likewise to have been formed by the evaporation of brines at a temperature of at least 50°.

The remarkable salt lake of Bahr Assal, near Tajúra, not far from the Red Sea, in North-Eastern Africa, offers an existing example of conditions such as would be adequate to produce, in some places, a salt like that of Vic, or Glauberite. This lake formed probably at one time a part of the Bay of Tajúra, from which it was separated by the protrusion of a basaltic dyke or reef, and since then has been gradually evaporating down until nothing now remains but a mass of compact white salt and some saturated mother liquor. The annual evaporation is now, of course, very small; but, being surrounded by a dry and waterless desert, and immense precipices of black basalt, the temperature at which the evaporation in summer takes place is very high. Major Harris states that when he was encamped on its banks in the beginning of June, the temperature under the shade of umbrellas and cloaks was 52°·2 (126° Fahr.).[14] Later in the season the temperature must have reached at least 60°. The temperature at night is almost as high as in the shade during the day, in consequence of the radiation of the black basaltic rocks. In deep lakes the great mass of the saline solutions could not attain so high a temperature as 50°; and even if the surface stratum did attain it, and that anhydrous sulphate of soda happened to be precipitated, it would re-dissolve as it passed through the cooler strata below. Such compounds could only be permanently formed, therefore, either in shallow lakes, on the margins of deep ones, or in the upper strata of what may have once been deep lakes, but which by evaporation and the deposition of common salt, had become shallow. The circumstances under which Glauberite has been found, harmonize perfectly with the theoretical conditions just stated, and which, as may be at once perceived, are not frequently found naturally in conjunction, and hence the comparative rarity of Thenardite and Glauberite. There is a great analogy between the salt deposit of Bahr Assal and the *salinas* of Chili, which are situated near the coast, and which were once connected with the latter. We may consequently expect to find on the margin of Bahr Assal the same curious variety of salts met with around the margins of the *salinas* alluded to, nitrate of soda perhaps excepted.

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[14] *Highlands of Æthiopia*, vol. I. p. 105. Further on he says, that fifty pounds of well packed spermaceti candles were so completely melted out of the box as to be reduced to a mere bundle of wicks during the short journey from Tajúra. "Even the Danákil, who from early boyhood have been accustomed to traverse the burning land of the Tehâma, never speak of it but in conjunction with the devouring element, of whose properties it partakes so liberally, and when alluding to the lake of salt, invariably designate it 'Fire'"—p. 121.

Hydrated sulphate of soda or mirabilite, on the other hand, must have been formed at temperatures below 35°, and this may take place, 1. by precipitation from a solution; 2. metamorphism of Thenardite or Glauberite by water; and 3. by pseudomorphosis. The glauber salt of Alcanadra, near Lodosa, in the valley of the Ebro, to which reference has already been made, appears from the report of M. Burat, as given by M. Dufrenoy, to have been formed by precipitation from a solution. To the same category belong the crystals of glauber salt found in the neighbourhood of the Aral Sea, the Astrakanite of the Karrduan lakes, and the similar salt found at Mendoza and other places in the Pampas of Buenos Ayres, and the salt described as Reussine, which is formed from the mineral springs of Sedlitz and Franzenbrunn in Bohemia. The glauber salt of the valley of the Jarama is undoubtedly due to the action of water upon the Thenardite constituting the main mass. The minerals known as Löweite and Blædite, which are hydrated combinations of sulphate of magnesia and sulphate of soda, are perhaps the result of a metamorphic action, which, although not producing true pseudomorphs, may, nevertheless, be included under that category.

Enough has been said to show that we can only explain the beds of sulphate of soda in the valley of the Jarama by supposing them to have been deposited in a shallow lake formed by inundations, and containing a comparatively pure solution of sulphate of soda, which gradually concentrated by evaporation until the temperature rose above 35°, at which crystals of Thenardite began to be precipitated. The problem of how the solution of sulphate of soda was formed, or rather how it was separated from the other salts which in natural water are usually associated with it, remains still unsolved, however. In the short description of the Kirghiz Steppes, which we have given from M. Nöschel, lakes of glauber salt are mentioned as having been formed where a particular bed of marly clay crops out, which abounds with the salt in question. These lakes are evidently mere catchment basins for the drainage of the bed in question If one of these dried down, as some of them do, a layer of sulphate of soda would be formed, which would be Thenardite if the temperature at which the salt crystallized was above 35°, and mirabilite if below that temperature.

How came the glauber salt in the clay? If we suppose a solution of mixed salts, instead of forming a clear lake, to impregnate a great mass of clay containing gypsum, the various reactions which we have described as taking place at different temperatures, would be greatly modified. Let us suppose a gypseous clay, impregnated with chloride of sodium, to be covered with snow for a considerable portion of each winter; the water which would drain away from the snow where it came in contact with the saline clay, would usually have a temperature below 0°. The salt dissolved by such water, would be able to decompose gypsum, and form chloride of calcium and sulphate of soda. The solubility of sulphate of soda being very little at temperatures below 0°, would crystallize out wherever concentrated solutions of salt happened to have acted upon the gypsum. In this case a partial separation of the two salts formed by the decomposition would be effected, because the chloride of calcium would diffuse itself, and in some cases may even drain away. When the whole of the snow has melted, and the temperature has risen somewhat, the sulphate of soda and chloride of calcium, which may be in contact, do not immediately redecompose each other, especially at temperatures below 20°. As the soil dries, capillary attraction brings up water from below, holding all the soluble salts of the soil in solution in proportions, depending not only upon their solubility and mass, but especially also upon the relative facility with which the solutions of each ascend capillary tubes. The latter, in fact, exert a kind of elective power upon a solution of mixed salts, which, although extremely minute when studied during a short time, becomes an important agent for separating salts in process of time. Sulphate of soda is a salt which has a relatively high capillary power, and during the day, when the temperature would be warm, its solubility would rapidly increase, so that a relatively large proportion of it would come to the surface. If heavy rain, but of short duration, should then fall, having a low temperature, the deliquescent salts, such as the chloride of calcium and magnesium, and the sulphate of magnesia and common salt, whose solubility does not diminish much between 30° and 0°, would be removed more rapidly than sulphate of soda. The latter would thus gradually accumulate in the soil, and would at last effloresce as at Bahia Blanca and the Kirghiz Steppes. If sulphate of magnesia existed in the soil as well as gypsum, the changes would be quite similar and more rapid, but the separation of the salts would not be complete until the whole of the magnesian salt would be decomposed.

The chief conditions, then, which should exist for the production of glauber salt in the soil are, 1. the impregnation of a rich, marly, gypseous soil with common salt, or with the addition of sulphate of magnesia; 2. a winter temperature somewhat below zero for a considerable time, or better still, a coating of snow for one or two months; 3. summer rains of short duration, a high summer temperature, and a general dryness of the atmosphere. But besides these, the phenomena would greatly depend upon a nice balance of conditions as to degree, alternation, and duration of temperature, quantity and duration of rain, relative proportions of the different salts in the soil, and of the density of the solution formed after each shower of rain, and, no doubt, many others also. But that such favourable circumstances may occasionally coëxist in some localities is proved by the Steppes of the Kirghiz, and the saline efflorescences of the Pampas and other localities. But similar changes take place more or less upon all saline steppe soils, so that sulphate of soda abounds in them at certain seasons. Some analyses of raw sodas, that is, the ashes of Halophytes of the Caspian Steppes, made by Professor Göbel,[15] seem to show that the quantity of alkaline sulphates varies very considerably with the seasons, as well as with the age of the plant. It is much to be regretted that we have not a seriés of analyses of the ashes of plants, and of the soluble salts of the steppe soils at different seasons and temperatures. The results would not only possess interest in connection with our present inquiry, but also throw much light upon the changes which take place in all soils to a greater or lesser extent.

Let us now see how far the conditions which we have stated coëxist, or did coëxist, in the valley of the Jarama. Many years ago, A. von Humboldt noticed the fact that Madrid rests upon gypsum in part, which, as well as the clays around, is somewhat saline. Salt, too, occurs, as is long known, at Villa Rubia, near Ocaña, south-west of Aranjuez. Again, we have the authority of Don J. Ezquerra del Bayo for the existence of considerable deposits of salt in the Tagus basin. It matters not for our purpose whether all, or indeed any, of these deposits are in the tertiary or in the cretaceous formations, provided it be proved that the clays forming the soil are impregnated with salt. Again, abundance of magnesia exists in the marly clays and in the lacustrine limestone which forms the upper tertiary deposits. The great river basins of central Spain must have consisted at one time of a series of great lakes, not unlike the Canadian lakes, during and at the close of the tertiary period. After the partial drainage of these lakes in the Tagus basin, and before the complete erosion of the river valleys, certain portions of country along the lines of the rivers must have been subject to periodic inundations, which formed shallow lakes like those now found along the course of the Mississippi and its confluents. The central table-land of Spain is subject to considerable extremes of temperature; in summer the temperature in the vega of the Jarama often exceeds 50°, while in winter it is sometimes covered with snow.[16] There is a certain periodicity in the rain-fall, so that during certain periods of the year the atmosphere is very dry. Plate II. shows, what one may have anticipated, that the country to the north, east, and west of the present vega of the Jarama, and of what was once the sulphate of soda lake, is higher, and drains towards the Jarama.

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[15] Reise nach den Steppen des südlichen Russlands 2ter Bd. S. 108.

Over the marly gypseous saline soil drained by the Jarama and its confluents, during the winter the temperature is sufficiently low to allow of the decomposition of the sulphates of the alkaline earths; while during the summer, the surface soil dries up, even the small torrential river beds become dry, so that all the capillary changes which we have above described could have taken place. During the heavy torrential rains the salts in the upper layer of the soil would be washed out, and with them would have been carried a quantity of fine mud. Part of both would be carried into shallow lakes, which during summer would gradually concentrate and become so shallow and concentrated that the temperature of the saline solution would rise beyond 35°. As the sulphate of soda would have gradually accumulated in the upper layer of the soil, as before described, the lakes formed by the inundations which lixiviated such a soil would hold almost entirely sulphate of soda in solution, and consequently when the latter would crystallize out at a temperature above 35°, it would be anhydrous. During the evaporation of the water a portion of the mud would gradually precipitate, and upon this would deposit a layer of anhydrous salt. As the fine mud or *greda* would not all deposit in a saturated solution, just as in the shallow lakes of the Kirghiz Steppes described by M. Nöschel, the crystals of Thenardite would always contain more or less intermixed clay.

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[16] At Madrid itself, in 1857, the maximum temperature observed in the shade was 39°4 Cent.; the coldest day had a mean temperature of 4° Cent.; the maximum cold reached —10°4 Cent. Only during three days the temperature remained fully below 0° Cent. But during six months (from November to April) frost may occur at any time. *Resumen de los trabajos Meteorologicos corr. al Año* 1854, *Verif. en el R. Observ. de Madrid*, 1857.

At length the whole body of water may have dried down, as we find actually taking place in the lakes around the Aral Sea. This drying down may have been annual, or, like the periodic lakes produced by the Mississippi, may occupy a very long time. We may look upon each of the groups of layers into which, as we have above described, the deposit may be divided, as the result of such a drying down, the thicker layer of mud which exists at the base of each group being the deposit formed before the point of saturation was reached. In this way we should expect to find the mud diminishing as we ascend, and the salt thicker and purer, which is exactly what we find, as we have above described. According as the deposit increased in thickness, it would become jointed from pressure, contraction, etc. Into these joints or cracks water would penetrate, and hydrate the salt along the planes of fracture; the hydrated salt thus formed would occupy more space than the anhydrous salt from which it was formed, and would consequently again seal up the cracks and prevent the further action of the water. At each successive inundation a portion of the upper layer forming the bed of the lake would become hydrated, and would dissolve in great part in the solution before it attained the point of saturation by evaporation. In this way a saturated solution would always be in contact with the bottom, and would to a great extent prevent the hydration of the subjacent salt. When at last the lake, as it approached saturation, attained a temperature of 33°, any undissolved hydrated salt at the bottom would be taken up by the solution, as it would then possess its maximum power of dissolution. A few degrees above this the solubility would again diminish, but the salt would now separate in an anhydrous condition. So in like manner any hydrated salt thrown down in winter would be redissolved in summer.

The length at which we have discussed the formation of alkaline sulphates from the sulphates of the alkaline earths, indicates sufficiently our predilection for that mode of explanation of the sulphate of soda of the Jarama. Nevertheless, it may be useful to indicate another source of the salt. It is well known that many salt springs contain glauber salt in considerable quantities; among these may be especially mentioned the celebrated warm springs of Carlsbad, which, according to Gilbert's estimate, pour out about 130,000 cwts. of carbonate of soda, and 200,000 cwts. of glauber salts annually. If such springs existed in the central plateau of Spain, they may have given rise to the formation of small lakes in which the water would become gradually saturated with different salts, the predominant one being sulphate of soda. During winter the rain would carry into such lakes a quantity of fine mud, which would form a layer upon the top of the salt which had crystallized out the previous year. As the water bearing this mud into the lake would dissolve much gypsum, the latter would be precipitated along with the mud, as it is less soluble in sulphate of soda than in pure water. Such a precipitation of sulphate of lime would of course take place, no matter whence the sulphate of soda came, so that the observation just made applies equally to the hypothesis which we have first discussed. In summer, anhydrous salt would be precipitated under the same conditions as we have already fully described. Indeed the only distinction between this hypothesis and the one before discussed, would be, that in the first the sulphate would be formed at the surface, and in the second at some depth in the earth. The latter is, however, so far unsatisfactory, that while it requires the agency of springs on a large scale, it really offers no solution of the real problem, and merely shifts it a stage backwards where we would have to call to our aid all the reactions of the first hypothesis.

In the commencement of this article we mentioned an important observation of MM. De Verneuil and De Lorière, that springs are numerous at the junction of the cretaceous and tertiary formations in the central plateau, which may hereafter be connected with these sulphate of soda deposits. We may also mention that such a sulphate of soda spring occurs at the salt works of Espartinas, near Aranjuez, and that crystals of Thenardite are formed during summer from the water of this spring. It was indeed to crystals thus formed that the name of Thenardite was originally given by Prof. Casaseca.[17] This spring may in fact be connected with some great deposit of sulphate of soda like that of the Jarama. This suggests a whole train of speculations regarding the changes which have taken place in the valley of the Tagus, which we cannot now discuss, because it would lead us too far, and especially it would be necessary first to minutely investigate the whole plateau.

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[17] Annal. de Chim. et de Phys., xxxii. 308.

In attempting to explain the origin of the sulphate of soda beds of the Jarama, we have assumed that the maximum and minimum temperature of central Spain does not essentially differ from that which prevailed at the period of their deposition. Whether our explanation be correct in all its details or not, there can be little doubt that this assumption is strictly true. Indeed the fact just noticed, that Thenardite is still formed during the summer in the very district where the great beds of it were anciently formed, is a decisive proof of the general correctness of the assumption. We have already stated that the beds of the Tagus basin are generally considered miocene, although some of the lower beds appear to be eocene. The beds of sulphate of soda must, however, be considered to be posterior to the whole series of beds described by Don Casiano de Prado, for pieces of the white lacustrine limestone, which he considers as the uppermost member, are found in great abundance in the clay both underlying and overlying the sulphate of soda. But in the absence of more complete evidence than we have at present, it would be premature to decide whether they are pleiocene or post-tertiary. In either case, the evidence which those beds afford of the climate of Spain having undergone no greater change during or since their formation, than perhaps what would result from the cultivation of the soil, which has everywhere a tendency to mitigate the cold of winter, is both interesting and important.

The remarkable analogy which exists between the hallurgical phenomena of the central plateau of Spain and those of th Aralo-Caspian steppes, suggests another interesting one between the two regions. Here we can do no more than point to it; to discuss it would be too great a digression from our proper subject. The plateaus of the Iberian Peninsula appear to have been elevated later than the nummulitic beds, but before the close of the eocene period. During the miocene period, the great river basins of the Ebro, Duero, Tagus, and Guadiana were, as we have above stated, great fresh-water lakes, which were gradually drained during the subsequent periods, according as the river valleys were eroded. The position of Spain itself, the close proximity of high chains of mountains, caused more rain to be precipitated than could be carried off by evaporation, and hence the rivers reached the sea. But, had the evaporation equalled the rain-fall, a series of continental basins would have been formed, from which no water would flow to the sea. In time, the salts brought into the lakes by the rivers, would have accumulated, and they would have become salt lakes. The salt and bitter lakes which exist still in the central plateaus, show us how this took place here and there on a small scale during the drainage of the great lakes.

Such are the changes which are even still in process in the Aralo-Caspian steppes. We have already stated that Von Helmersen considers the beds of this region to be marine eocene. After the deposition of these beds, the region appears to have become dry land, and, perhaps, to have remained so during the miocene and pleiocene periods, when it began to sink again below the level of the sea, which, in consequence of intervening high land, could not flow over it. It has, however, become the catchment basin of a large river system, the waters of which have accumulated in the Aral and Caspian Seas. The small quantity of salt in the latter shows that it was once fresh, and that now it is becoming salt by the gradual accumulation of the salts brought in by the rivers. We may admit that a small salt sea may have existed in the deepest part of the depression, a relic of the eocene sea, and that the gradual increase of water diluted this salt water. In any case, the salt of the Caspian Sea must now be increasing absolutely, if not relatively to the amount of water. But, if the opinion be correct that the water of the whole region is slowly diminishing, that is, that the evaporation exceeds the supply, then the relative as well as the absolute saltness of the Caspian Sea must be increasing.

The preceding observations suggest an important matter for the consideration of geologists, with a few observations upon which we shall conclude. One of the most universally diffused rocks is common salt. It occurs in every formation, from the Silurian to those now in progress, and is met with in almost every part of the globe, and often in immense masses. The quantity dissolved in the ocean is enormous. Taking an old and rough estimate of Breislak, it would amount to a mass sufficient to form a globe of above 135 miles in diameter. This quantity must have greatly fluctuated in different geological periods. Changes of level of land, the elevation of mountain chains, etc., must have isolated parts of the sea; these dried down when the evaporation exceeded the supply of water, and left the salt. It is in this way that all the great deposits of salt were formed,—an opinion which is quite independent of any hypothesis which may be selected to explain the first origin of salt.

Every rock is acted upon by water, and in time will decay. If this be so with granite and quartzite, how much more so is it true of common salt? Every spring which rises from salt beds, carries away to the ocean large quantities of it. The quantity thus carried away annually is really enormous, and in every formation we may find evidence of salt that had once existed but has dissolved out. Sometimes the removal has been so slow that something else was substituted for the salt, as in the case of the remarkable thin beds of limestone in the form of rock-salt, in the muschel-kalk of the Weser, described by Hausmann and Strüver.[18] Generally, however, nothing was left, and as the salt was removed, the superincumbent rocks sunk. When we recollect that rock salt forms sometimes masses 200 to 300 feet in thickness, there can be no doubt that in the crystallization and slow resolution of common salt, we have a dynamic agent of great power, and one, too, which is capable of explaining many phenomena of dislocation and faulting, apparent conformability, etc., which have hitherto been inexplicable upon any simple rational hypothesis in conformity with existing cosmical phenomena.

This dynamic agency has been frequently put forward by chemists; on the other hand, geologists have made numerous calculations to prove that the quantity of matter carried away in solution by such springs as Carlsbad would even in ten thousand years be trifling in comparison with the faults, valleys, etc., which we find in the localities where they occur. That the chemists have attributed too much power to such agencies may be readily granted; but, on the other hand, the geologists have depreciated their effects, because they have estimated them by the results which they could produce in comparatively short periods of time. Now, however, that the value of geological time is better understood, we have no doubt that hallurgical phenomena will receive that attention from a mechanical, as well as from a chemical point, which their immense importance deserves.

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[18] Bischoff—Lehrbuch der chemischen Geologie II. 3, pp. 1686-1687.

ON THE CHEMICAL COMPOSITION
OF A
# LACUSTRINE DOLOMITIC LIMESTONE
FROM THE PROVINCE OF MADRID.

NOTE

ON A

LACUSTRINE DOLOMITIC LIMESTONE.

IN the foregoing paper "On the Deposit of Sulphate of Soda in the valley of the Jarama", a white or grayish-white silicious dolomitic limestone was frequently mentioned. It appears to occur extensively in the basin of the Tagus, and a similar rock in the basin of the Duero. Along with the granite of the Guadarrama range, it is extensively used as a building material at Madrid. Its fine texture and beautiful grayish-white colour, which it appears to preserve indefinitely when exposed to the air, renders it a valuable material for ornamental carved stone work, and even statuary. The presence of magnesia and silica in considerable quantities in a freshwater limestone is so unusual, that an analysis of it may be interesting.

It is extensively worked near Colmenar de Oreja, which is situated on the high ground to the east of the sulphate of soda deposits, and between the valleys of the Jarama and upper Tagus. Lumps of it are abundant in the beds of clay and gypsum underlying and overlying the beds of sulphate of soda. It would thus seem that part of the valley of the Jarama has been eroded out of beds of this rock. The specimens examined were from this source.

A large lump of it showing perfectly sharp fractures and no appearance of having been rolled, was not of uniform texture or colour. One part of it was harder and closer than the rest; the colour of this part was grayish-white, and broke with a distinct conchoidal fracture, exactly like lithographic stone, which it resembles very much, and may no doubt be used for such a purpose. The other and smaller part was not so close in the grain; its appearance was much more chalk-like, and its colour much paler and having more of a yellow tinge in it.

When a fragment was treated with hydrochloric acid, it slightly effervesced, but the acid penetrated very slowly, especially the harder part, and a fragment one inch long and three-eighths of an inch thick, treated for about two months with concentrated chlorhydric and sulphuric acids, which were almost every day for four or five hours at a temperature of 80° Cent., and often higher, had not lost all its carbonates. When powdered it was decomposed with great facility by chlorhydric acid, which dissolved the carbonates of lime and magnesia, and left a grayish powder, which, when burnt, was a beautiful white meal, which readily dissolved in a solution of caustic potash. The solution was complete, except a few floculi, which looked like a very acid silicate of alumina, for on evaporating the solution and fusing the residue, then decomposing the fused mass with chlorhydric acid, and heating strongly to render the silica insoluble, ammonia and chloride of ammonium precipitated after long standing very slight floculi, which gave the characteristic reaction of alumina with salts of cobalt. The solution, after the separation of the alumina, gave a precipitate of ammonio-magnesian phosphate. The potash solution of the silica of every fragment analysed contained some magnesia in solution. No trace of organization could be detected in the silicious residue, even with a magnifying power equal to 590 diameters. It appeared, as seen in the microscope, to consist of perfectly amorphous small irregular opaque lumps, such as would be obtained by drying a gelatinous mass.

The following table contains the result of the analysis of several fragments, the denser ones being distinguished from the paler coloured and more porous ones:—

	DENSE.		POROUS.		
	I.	II.	III.	IV.	V.
CaO,CO_2 . .	32·767	33·839	39·502		
MgO,CO_2 . .	21·746		26·460		
FeO,CO_2 . .	0·813		0·782		
CaO,SO_3 . .	Slight trace,		0·391		
HCl, . .	„		Minute trace.		
S,O_2 . . .	39·058	38·92	27·870	29·25	25·830
MgO, as Silicate, .	0·400		0·432		
Al_2O_3 as Silicate, .	Trace.		Trace,		
HO, . . .	5·267		4·356		
Organic Matter, .	0·020		Not determined.		
	100·071		99·793		

From the preceding numbers it would appear, that the difference between the dense and porous rock is due to the relative proportion of silica; it also appears from the foregoing that the silica is hydrated. The ratio of water and silica in No. I. might be represented by the formula $3SiO_2,HO$. In the porous part there is more water than this formula would represent; this may, however, be due either to the hygroscopic water, or to some slight trace of carbonic acid being driven off from the magnesia. The ratio of the lime and magnesia in both specimens, is practically the same, and may be represented by $9CaO,CO_2+8MgO,CO_2$. In both I and III. the actual quantity of magnesia is somewhat greater than what this formula would require, so that it approaches almost to true dolomite.

It would appear, therefore, that this rock is a dolomitic mud, permeated by amorphous hydrated silica, a composition which completely explains its durability.

The existence of meerschaum, or hydrated silicate of magnesia, $2MgO,3SiO_2+2HO$, accompanied by halb opal, a variety of hydrated silica, calcedony and hornstone in a marl bed at Vallecas, near Madrid, and likewise in the basin of the Duero, suggests a connection between those minerals and the silicious dolomite. Such a connection is made more probable by the occurrence of fossils of *Helix*, which, with many species of fresh-water shells, are abundant in the lacustrine limestone of the central plateau, converted into meerschaum. Another fact which favours it is the occurrence of pseudomorphs of meerschaum after calcite in the druses of the former, observed by M. De Amar.[1] Breithaupt does not give the form of calcite, and as he complains that there was no detailed description in his original authority, it is probable M. De Amar does not mention it. It may be that the form was a rhombohedron, and was not calcite, but dolomite spar, the metamorphosis of which into hydrated silicate of magnesia may be easily explained, while that of pure calcite cannot.

It is well known that silica in contact with carbonates of lime and magnesia, held in solution in water by carbonic acid, gradually combines with them, but especially with carbonate of magnesia. If this takes place between anhydrous quartz and the earthy carbonates, it must take place with great facility when the silica is hydrated. In the dolomite under examination, a small quantity of magnesia is indeed already combined with the silica. If it were to be acted upon by water holding carbonic acid in solution, it is probable that the whole of the lime would be gradually removed, while the magnesia would slowly combine with the silica. If the whole of the lime of No. I. were removed, the magnesia would be nearly sufficient to convert the silica into meerschaum. In No. III. the magnesia would be far more than sufficient. In the former case calcedony or halb opal may be formed, minerals which, as has been above mentioned, are associated with meerschaum: in the latter case, carbonate of magnesia would be carried off along with carbonate of lime. Calcite is also found with the meerschaum, thus completing the chain of evidence.

But it is not at Vallecas alone that meerschaum appears to be connected with silicious limestone. At Coulommiers, and at Chenevières, near Paris, a bed of hydrated silicate of magnesia, from $0^{m}\cdot20$ to $0^{m}\cdot40$ thick, occurs in the upper marls of the *Calcaire de la Brie*, and having the same laminated structure as the marls. The peach-coloured hydrated silicate of magnesia, called

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[1] Breithaupt—Die Pseudomorphosen, S. 258.

Quincyte, which occurs in the midst of the fresh water limestone of Mehun and of Quincy, is very like the Vallecas mineral in composition. And lastly, the celebrated deposit of meerschaum at Kiltschick, in Natolia, consisting of a bed $2^{m.}$ thick, associated with a whitish-gray limestone, appears to offer a considerable analogy to the Spanish mineral. We do not know whether any one has analyzed the limestones associated with those silicates of magnesia, but it would be interesting if they were found to be dolomitic.

APPENDIX.

APPENDIX.

◆

On some curious molecular changes produced in Disilicate of Zinc, and some of its compounds with carbonates, by the action of heat. By W. K. SULLIVAN.

IN a note which I communicated to the Royal Irish Academy,[1] I gave an account of some very curious molecular changes which were produced by the action of heat on the peculiar pisolithic compounds of disilicate and dicarbonate of zinc, described in the preceding paper, and for which the general formula $m(2ZnO,SiO_2)+n(2ZnO,CO_2)+pHO$, was proposed. As the phenomena appear to support the isomorphism of the carbonate and silicate of zinc, and are, although their cause be still obscure, very interesting, I think it will be useful to complete the subject of the preceding paper by printing here the substance of the note communicated to the Academy.

When fragments of the pisolithic silicates were heated to drive off the hydrated water, they became of a bright lemon yellow colour, passing into orange; on cooling, the colour almost wholly faded. The phenomenon is just like what is observed with white oxide of zinc, except that the latter never yields so bright a yellow as the silicates do. The change appears to take place at a little above the temperature of melting lead; at a redness just visible at daylight the colour of the fragments changes to green, which is sometimes of a deep verdigris-green. On removing the lamp for a moment from under the crucible containing the fragments, they suddenly became yellow. When the temperature was increased by means of a blow-pipe, the colour again became yellow. On allowing the crucible then to cool, the colour of the fragment changed successively from light yellow to verdigris-green, then to bright orange-yellow, which became paler as the cooling proceeded, until the fragments became nearly white. On being heated, the chromatic scale was reversed, so that the changes could be observed both during the heating and cooling. The changes took place very rapidly, accompanied by a kind of phosphorescent glow, which was very beautiful, and could be repeated apparently any number of times with the same fragments. The latter circumstance shows that the phenomenon can take place after the loss of carbonic acid. When the mineral is in fragments the phenomenon is best seen; when reduced to very fine powder, it almost wholly disappears. Silicate, which contains hardly any carbonate, and which it is very difficult to reduce to a very fine powder, exhibits it better when powdered than the silicates containing very little silica, although the latter act better in fragments. The hydrocarbonate $3(ZnO,CO_2)+5(ZnO,HO)$, described in the preceding paper, does not exhibit the whole chromatic phenomenon; it merely becomes yellow, like oxide of zinc; some specimens, however, show faint traces of green. In the reniform masses, consisting of alternate shells of disilicate and the hydrocarbonate in question, so extremely thin that they can scarcely be distinguished by the eye, the separate layers may at once be recognized on heating some fragments, by the alternate lines of green and whitish yellow, the former being the silicate, and the latter the hydrocarbonate.

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[1] Proceedings of the R. I. Academy, vol. viii. p. 55.

The development of the yellow colour is not peculiar to either carbonate or silicate of zinc, but belongs to the oxide of zinc; and it is not due to any impurity, for oxide prepared with the greatest care, and perfectly free from any trace, capable of being indicated by reägents, of iron, lead, or cadmium, becomes yellow when heated. But the green colour, and especially the ascending and descending alternations of yellow, green, yellow, appear, so far as I have seen, to be peculiar to the disilicate, and what in the preceding paper have been considered to be compounds of disilicate and dicarbonate. Both colours, too, may be observed in nature; but only in the neutral carbonate. Bright lemon yellow Smithsonite is very frequently met with, especially in reniform mineral; and at Merodio, lemon yellow reniform Smithsonite, of exactly the same composition as the pure translucent Smithsonite which accompanies it, is found associated with the leek green fibrous carbonate described in the preceding paper at p. 95. The change of yellow to green may be connected with the hemi-morphism to which the pyro-electric properties of disilicate of zinc are due. If this were so, it would not only imply that the dicarbonate was also hemi-morphic, but that the molecular grouping to which the hemi-morphism of the disilicate of zinc is due, exists to some extent in the molecules before they begin to form crystals, because the pisolithic compounds are perfectly colloid. It may be objected, that as the change takes place in the compounds just mentioned after the carbonic acid has been driven off, the phenomenon can have no connection with that of the hemi-morphism of dicarbonate. This objection is, however, we think, met by the fact, that when fragments of a mineral containing carbonic acid are heated so as to drive off the acid, they still retain their original form, and consequently any phenomenon dependent upon form would not be much affected by the loss of the carbonic acid; an opinion which is borne out by the fact that the phenomenon is not produced by the powdered mineral.

Whatever be the cause of the phenomenon, it is extremely curious; and the fact of the complete chromatic change being confined to the disilicate, and to the pisolithic compounds which have been supposed to be formed of dicarbonate and disilicate, appears to me to support the formulæ assigned to those bodies in a very curious way.

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[With a view to facilitate reference, all the genera and species of fossils mentioned in this work have been alphabetically arranged under the word "Fossil"; all names of places under "Geographical Names"; all mineral species under "Mineral"; all mines under "Mines"; and all names of persons under "Names of Persons".

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